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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

The present document is based on input provided by various European projects, AutoNet 2030, CODIS, Truck Platooning Challenge, ENSEMBLE, TIMON, HIGHTS, Intercor, C-ROADS, VRUITS (improving the safety and mobility of Vulnerable Road Users through ITS applications), PROSPECTS (Proactive Safety for Pedestrians and Cyclists), XCYCLE (Advanced measures to reduce cyclists' fatalities and increase comfort in the interaction with motorised vehicles), SafetyCube (Safety CaUsation, Benefits and Efficiency) and SENIORS (Safety Enhanced Innovations for Older Road userS). The present document considers input from liaising with SDOs such as SAE, IEEE, CEN/ISO and 3GPP.

Modal verbs terminology

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"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Introduction

The present document considers Multi-Channel Operation (MCO) technology agnostic concepts for the realization of single technology solutions. The present document does not consider mixed IEEE and 3GPP based ITS technologies MCO concepts since multiple technology coexistence solutions are needed to realize such concepts, which are currently not available.

1 Scope

The present document provides an overview of the potential requirements for Multi-Channel Operation (MCO) in C-ITS and the technical capabilities and limitations of C-ITS with respect to MCO. It further proposes a concept for MCO that supports a multitude of C-ITS applications, services and functions. Finally, the present document derives recommendations to update relevant ETSI ITS specifications related to MCO and develop new ones.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

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

active state: state in which the ITS-S or the road user is actively participating in Road Traffic

actors: external entities (human, or other systems) that interact with the system

NOTE: The system affects and is affected by the behaviour of actors; therefore, these relations are described in the use case descriptions.

ad-hoc: operating mode in which an RLAN device establishes a temporary wireless connection with other RLAN devices without a controlling network infrastructure [i.27]

application: a technical implementation of the supported use case(s) residing at the Application layer in the ITS Architecture

NOTE: Applications could also provide information which can be used by other applications. A facilities layer message service which includes message generation triggering rules and from which the message generation is not primary triggered by other applications, such as most awareness services, is conceptually considered to be an application for its triggering part and a service for its message generational part.

awareness (in road traffic)**:** situation when road users and roadside infrastructure are informed about each other's dynamic state

NOTE: See ETSI EN 302 637-2 [i.6].

broadcast: unidirectional point-to-multipoint mode of transmission, and a single sender transmits protocol units to all recipients

Channel Busy Ratio (CBR): time-dependent value between zero and one representing the fraction of time that a single radio channel or sub-channel is busy with transmissions

NOTE: The definition of busy depends on the deployed access layer technology.

C-ITS: ITSs, where the cooperation between two or more ITS sub-systems (personal, vehicle, roadside and/or central) enables and provides ITS user services to serve the C-ITS Methodology

C-ITS methodology: sharing transport (traffic situation) related information among traffic stakeholders, openly, to realize common traffic safety and traffic efficiency related benefit for all

C-ITS-S: ITS stations which implements the C-ITS Methodology and related C-ITS Domain trust model

C-ITS-U: any person, group, organization or automated system

constellation: a group of ITS-Ss that communicate with each other exchanging data

NOTE 1: ITS-Ss mostly have different positions and be part of and active in different constellations but in general not necessary in all as not all ITS-Cs need to overlap.

NOTE 2: For example, ITS-Cs in Australia do not overlap with ITS-Cs in China.

data provider: role that a C-ITS-S has when it communicates information

data user: role that a C-ITS-S has when it consumes information received

decentralized congestion control: set of mechanisms for ITS-S to maintain network stability, throughput efficiency and fair resource allocation to ITS-S using ITS-G5 access technology

domain: common area of interest and/or ownership

ECO-System (ICT specific)**:** ICT ecosystem which encompasses the policies, strategies, processes, information, technologies, applications and stakeholders that together make up a technology environment for a country, government or an enterprise

ITS: technical solution, platforms and applications that improves the quality of transportation, or achieves other outcomes based on applications that monitor, manage or enhance transportation systems

NOTE: Systems such as Real-time parking management, Electronic toll collection, Emergency vehicle notification systems, Automated road speed enforcement, Speed alerts, RFID in freight transportation, Variable speed limits, E-Call, Dynamic traffic light sequence, Collision avoidance systems and Cooperative-ITS as defined in clause 5.2.2.3.

ITS-G5: access technology to be used in frequency bands dedicated for European Intelligent Transport Systems as defined in ETSI EN 302 663 [i.22]

ITS-S: generic ITS station able to support any selected ITS application

LTE-V2X: access technology to be used in frequency bands dedicated for European Intelligent Transport Systems as defined in ETSI EN 303 613 [i.23]

Multi-Channel Operation (MCO): operation of C-ITS using more than one physical channel, possibly involving channel coordination

multicast: unidirectional point-to-multipoint mode of transmission, and a single sender transmits protocol units to a group of recipients

object class: class identifying the different type of objects such as vehicles and pedestrians

offloading: transmission of Data in a channel other than originally intended

oth: overload threshold

roadside ITS-S: ITS station in a roadside ITS sub-system

scenario: chronological sequence of a set of scenes, including sequence of actions and events and goals and intentions of actors get apparent

see through of passing: use case by which a proceeding vehicle provided raw sensor data such as a video signal about what is visible in front of the proceeding vehicle to following vehicles such that the following vehicles can take automation or safety related measures

service: service residing in the facility layer according to the ETSI EN 302 665 [i.8]

service provider: legal identify, organization of business providing subscribers to have access to a provided user service or function

short-range: several meters to several 100 meters. Compared to Near-Field: several centimetres to several meters

situation: description of relevant scenery (everything presents within a static snapshot, including the functional actors and physical situation at a given moment) considering (driving) functions related goals and values

NOTE: Including dynamic elements, scenery and self-representation.

technology agnostic: being unbiased towards the use of specific technologies

trust-domain: domain that the system trusts to authenticate users

trust model: specific mechanisms that are necessary to respond to a specific threat profile

NOTE: A trust model should include implicit or explicit validation of an entity's identity or the characteristics necessary for a particular event or transaction to occur.

unicast: unidirectional point-to-point mode of transmission, one sender transmits protocol units to one other recipient

use case: description is a function description including the desired behaviour (of the expecting system and the actors) specification including definition of one or more supported scenarios

user service: user service is the service provided by an implemented Application to users e.g. humans or systems

V2X: vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and/or infrastructure to vehicle (I2V), or vehicle to network (V2N) and/or network to vehicle (N2V) communication

virtualization: decoupling of the direct coupling of the logical and physical channels

3.2 Symbols

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

CBR	Measured channel busy ratio
d_{ji}	Euclidean distance between node i and node j T_{on} Duration of a transmission
d_{STEP}	Discretization interval (granularity) for the calculation of the performance metrics

L_{ji}^{adj}	Portion of power interfering in the channel used by node *i* from a signal in the channel used by node *j*
$P_{\text{i\_ACL}}$	Interference power from ACL effect at the transmitter
$P_{\text{i\_ACS}}$	Interference power from the ACS effect at the transmitter
P_{ji}^{MCO}	Interference due to MCO perceived by node *i* from node *j*
P_{ji}^{r}	Power received at the position of node *i* from node *j* within the channel used by node *j*
$P_{\text{TX\_int\_eff}}$	Effective Interference TX power, sum of $P_{\text{i\_ACL}}$ and $P_{\text{i\_ACS}}$
T_{busy}	Period of time within $T_{CBR\text{-}ITSG5}$ when the strength of received signals exceeds a given threshold
$T_{CBR\text{-}ITSG5}$	Duration of the time interval for the calculation of the channel busy ratio
$T_{gen\text{-}DCC}$	Minimum inter-packet generation interval set by DCC in ITS-G5 based systems
t_{pack}	Packet duration
T_{sys}	ITS Station Time
t_{target}	Target time gab

3.3 Abbreviations

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

5GAA	5G Automotive Association
ABS	Anti-skid Braking Systems
AC	Access Category
ACC	Adaptive Cruise Control
ACK	Acknowledgment
ACL	Adjacent Channel Leakage
ACLR	Adjacent Channel Leakage Ratio
ACR	Adjacent Channel Rejection
ACS	Adjacent Channel Selectivity
AEF	Agriculture industry Electronics Foundation
AETA	European Automotive and Telecoms Alliance
AFV	Automated Fueling Vehicle
AI	Artificial Intelligence
AID	Application Identifier
AIFS	Arbitration InterFrame Space
AS	Agriculture Safety
ASIL	Automotive Safety Integrity Level
BPSK	Binary Phase-Shift Keying
BSA	Basic Set of Applications
BSM	Basic Safety Message
BSP	Basic System Profile
BTP	Basic Transport Protocol
BWA	Broadband Wireless Access
CA	Cooperative Awareness
CACC	Cooperate Adaptive Cruise Control
CAM	Cooperative Awareness Message
CAS	Cooperative Awareness Service
CBR	Channel Busy Ratio
CBTC	Communications Based Train Control
CC	Congestion Control
CCAD	Connected and Cooperative Automated Driving
CCAM	Connected and Cooperative Automated Mobility
CCDF	Complementary Cumulative Distribution Function
CCH	Control Channel
CEPT	European Conference of Postal and Telecommunication Adminstrations
C-ITS	Cooperative Intelligent Transportation Systems
C-ITS-S	Cooperative Intelligent Transportation Systems Station
C-ITS-U	Cooperative Intelligent Transportation Systems User
CIA	CAM Information Aggregation
CP	Collective Perception
CPM	Collective Perception Message
CPS	Collective Perception Service

CRC	Cyclic Redundancy Check
CSMA	Carrier-Sense Multiple Access
CUS	Certificate Updating Service
CUM	Certificate Updating Message
C2C-CC	Car 2 Car Communication Consortium
CW	Continues Wave
CW	Continues Window
DCC	Decentralized Congestion Control
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DP	Diagnostic Port
DP	Data Provider
DU	Data User
DSC	Dynamic Stability Control
DSCO	Detected Safety-Critical Object
EC	European Commission
ECC	European Cooperation Centre
EDCA	Enhanced Distributed Channel Access
ERM	EMC and Radio Spectrum Matters
EDRs	ETSI Drafting Rules
EIRP	Equivalent Isotropic Radiated Power
ERS	Empty Road Segment
EU	European Union
EV	Electrical Vehicle
FA-SAP	Facilities-Applications Service Access Point
FFT	Fast Fourier Transformation
FSR	Functional Safety Requirement
FTT	Fault Tolerance Time
GCM	GNSS Correction Message
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPC	GNSS Positioning Correction
GN	GeoNetworking
HARQ	Hybrid Automatic Repeat Request
HFC	High Frequency Container
IEC	International Electrotechnical Commission
IPG	Inter-Packet Gap
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IMZM	Interference Management Zone Message
IS	Intersection Safety
ISA	Integral Safety Awareness
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
IVI	Infrastructure toVehicle Information
IVIM	Infrastructure toVehicle Information Message
IVS	In-Vehicle Signage
KPI	Key Performance Indicator
LCA-B	Lane Change Assist at Bus
LFC	Low Frequency Container
LOS	Line Of Sight
MAC	Media Access Control
MAP	Map
MAPEM	MAP Extended Message
MC	Maneuver Coordination
MCO	Multi-Channel Operation
MCM	Maneuver Coordination Message
MCS	Maneuver Coordination Service
MIB	Management Information Base
MLME	MAC Layer Management Entity
NC	Not Connected
NF-SAP	Networking-Facilities Service Access Point

NLOS	Non-Line Of Sight
NR	New Radio
NR-V2X	New Radio V2X
NTIA	National Telecommunication & Information Administration
OSI Model	Open Systems Interconnection Model
PA	Position Accuracy
PAI	Position Accuracy Improvement
PAM	Platooning Awareness Message
PAS	Position Augmentation Service
PCM	Platooning Control Massage
PD	Path prediction
PDB	Packet Delay Budget
PH	Path History
PHY	Physical Layer (device or protocol)
PL	PathLoss
PoTi	Position and Time
PPPP	Proximity services Per-Packet Priority
OR	Protection Ratio
PRB	Physical Resource Block
PRR	Packet Reception Ratio
PSD	Power Spectrum Density
PSD	Platform Screen Doors (Urban Rail)
PSCCH	Physical Sidelink Control Channel
PSSCH	Physical Sidelink Shared Channel
PTW	Power Two-Wheeler
QAM	Quadrature Amplitude Modulation
QM	Quality Management

NOTE: As ASIL level, only standard QM is required).

QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RF	Radio Frequency
RLAN	Radio Local Area Network
RRM	Roadside Ranging Message
RRS	Roadside Ranging augmentation Service
RSSI	Receiver Signal Strength Indicator
RSU	Road Site Unit
RTCM	Radio Technical Commission for Maritime services
RTK	Real Time Kinematic
RWW	Roads Works Warning
RX	Receiver
SA	Service Announcement
SAE	Society of Automotive Engineering
SAEM	Service Announcement Essential Message
SAMCO	Service-Actuated Multi-Channel Operation
SAS	Service Announcement Service
SCF	Store-Carry-Forward
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
SCH	Service CHannel
SDO	Standardization Development Organization
SINR	Signal to Interference and Noise Ratio
SOTIF	Safety Of The Intended Function
SP	Service Provider
SPAT	Signal Phase And Timing
SPATEM	SPAT Extended Message
SRD	Short Range Device
SREM	Signal Request Extended Message
SSEM	Signal request Status Extended Message
TC	Traffic Class
TC	Technical Committee
TCP	Transmission Control Protocol

TFEU	Treaty on the Functioning of the European Union
TS	Technical Specification
TV	Target Vehicle
TX	Transmitter
UE	User Equipment
URS	Urban Rail Safety
VAM	VRU Awareness Message
VBS	VRU Basic Service
VMS	Variable Message Sing
VRI	Traffic Control System
VRU	Vulnerable Road User
V2X	Vehicle-to-Anything
WAVE	Wireless Access in Vehicular Environments
WLAN	Wide Local Area Network
WSA	WAVE Service Advertisement
ZC	Zone Controller

4 Background

4.1 Introduction

Different approaches have been used for the realization of Cooperative ITS (C-ITS) applications in different regions of the world. Clause 4.2 gives an overview of the developments in Europe.

4.2 European developments

In the late 90s, it was recognized that information exchange among vehicles and with road infrastructure can help improve road safety, road efficiency and support transport automation. In Europe in-depth spectrum analyses were based on findings by the National Telecommunication & Information Administration (NTIA) in the USA [i.1], which had allocated 85 MHz for C-ITS. In Europe this led to investigations performed by ETSI TC ERM in the period of 2004-2006, leading to two reports, i.e. the ETSI TR 102 492-1 [i.2] in 2005 and ETSI TR 102 492-2 [i.3] in 2006. In the ETSI TR 102 492-1 [i.2] an initial set of safety related applications was identified (see Table 1), which was included in the ETSI TR 102 638 [i.4] that defines a Basic Set of Application (BSA) ETSI TR 102 638 [i.4] and ETSI TR 102 492-1 [i.2] and ETSI TR 102 492-2 [i.3] were the basis for the realization of the European spectrum regulation most importantly covered in the EC Decision 2008/671/EC [i.5] (see Figure 1) from 2008 and the amended version EC implementation Decision C(2020)6773/F1 [i.74].

Table 1: ETSI TR 102 492-1 [i.2] List of Release 1 safety related applications

Application	Description
Cooperative Collision Warning	Cooperative collision warning collects surrounding vehicle locations and dynamics and warns the driver when a collision is likely.
Work Zone Warning	Work zone safety warning refers to the detection of a vehicle in an active work zone area and the indication of a warning to its driver.
Approaching Emergency Vehicle Warning	This application provides the driver a warning to yield the right of way to an approaching emergency vehicle.
Traffic Signal Violation Warning	Traffic signal violation warning uses infrastructure-to-vehicle communication to warn the driver to stop at the legally prescribed location if the traffic signal indicates a stop and it is predicted that the driver will be in violation.
Emergency Vehicle Signal Pre-emption	This application allows an emergency vehicle to request right of way from traffic signals in its direction of travel.
In-Vehicle Signage	The in-vehicle signage application provides the driver with information that is typically conveyed by traffic signs.
Road Condition Warning	Road condition warning is used to provide warning messages to nearby vehicles when the road surface is icy, or when traction is otherwise reduced.
Low Bridge Warning	Low bridge warning is used to provide warning messages especially to commercial vehicles when they are approaching a bridge of low height.

Application	Description
Highway/Rail Collision Warning	Railroad collision avoidance aids in preventing collisions between vehicles and trains on intersecting paths.
Wrong Way Driver Warning	This application warns drivers that a vehicle is driving or about to drive against the flow of traffic.
Emergency Electronic Brake Lights	When a vehicle brakes hard, the Emergency Electronic Brake light application sends a message to other vehicles following behind.
Left Turn Assistant	The Left Turn Assistant application provides information to drivers about oncoming traffic to help them make a left turn at a signalized intersection without a phasing left turn arrow.
Curve Speed Warning	Curve speed warning aids the driver in negotiating curves at appropriate speeds.
Vehicle-Based Road Condition Warning	This in-vehicle application will detect marginal road conditions using on-board systems and sensors (e.g. stability control, ABS), and transmit a road condition warning, if required, to other vehicles via broadcast.
Low Parking Structure Warning	This application provides drivers with information concerning the clearance height of a parking structure.
Lane Change Warning	This application provides a warning to the driver if an intended lane change may cause a crash with a nearby vehicle.
Highway Merge Assistant	This application warns a vehicle on a highway on-ramp if another vehicle is in its merge path (and possibly in its blind spot).
Cooperative Glare Reduction	This application uses C2C-C to allow a vehicle to automatically switch from high-beams to low-beams when trailing another vehicle.
Intelligent Intersection Control	Alerts driver to other vehicles at intersections.

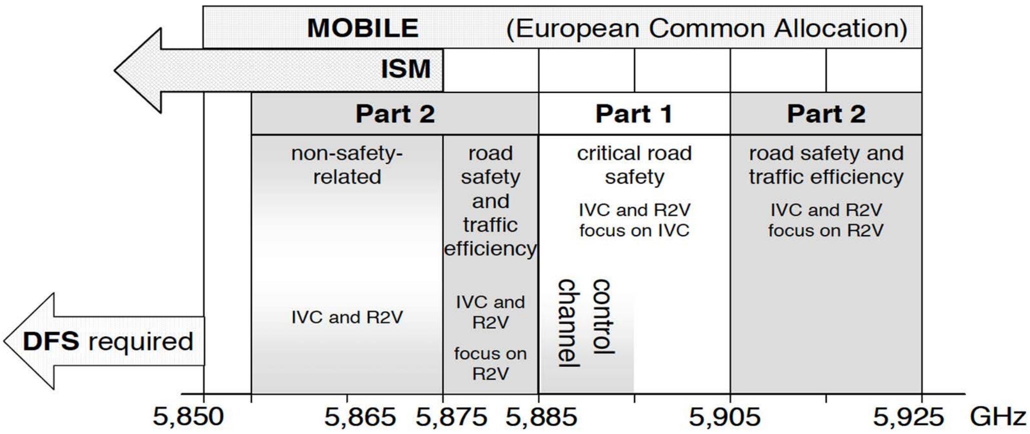

Figure 1: ETSI TR 102 492-2 [i.3] proposed spectrum allocation

The ETSI TR 102 638 [i.4] identifies the initial cooperative C-ITS applications which realize safety use cases and have been functionally as well as technically tested in various R&D projects in Europe. To support these applications, information exchange is realized based on two key basic message services: the Cooperative Awareness service (CA) as specified in ETSI EN 302 637-2 [i.6], which provides awareness of neighbouring C-ITS-S, and the Decentralized Environmental Notification service (DEN), specified in the ETSI EN 302 637-3 [i.7], enabling the notification of safety related situations detected by a transmitting C-ITS-S.

To accommodate safety related and non-safety related ITS information exchange European regulation EC Decision 2008/671/EC [i.5], EC implementation Decision C(2020)6773/F1 [i.74] identified two different allocations:

- 5 safety related channels between 5 875-5 925 MHz designated to facilitate the required information exchange; and
- 2 non-safety related channels in 5 855-5 875 MHz allocated for non-safety.

Spectrum aspects are further discussed in clause 5.2.3.

The initial CA and DEN services were realized and tested in a single channel (5 895-5 905 MHz). The tests have shown that a single channel is sufficient for the services usage to support the realization of the Release 1 applications realizing Release 1 use cases, at least before a high technology penetration is reached. During the development and testing of the CA and DEN two other services not identified in the ETSI TR 102 638 [i.4] were additionally developed: the basic In-Vehicle Signage application, supported by the In-Vehicle Information (IVI) service (ISO TS 19321 [i.9]), and the traffic light information applications supported by the Signal Phase and Timing (SPAT) and map (MAP) services (ISO TS 19091 [i.10]). European projects have proven the correct operation of these services. European R&D projects such as CVIS [i.11], Safespot [i.12], sim^{TD}[i.13], Drive-C2X [i.82], Preserve and Scoop@F [i.14] showed that the information exchange required for the operation of these Release 1 [i.25] services already utilize the capacity of a single channel and that additional applications require the use of additional spectrum (channels).

Starting from 2017, Release 2 related user services, related applications, facilities services and underlaying technologies are being developed. Besides safety related C-ITS, the new user services also include automation related functionalities such as those identified by the CCAM platform [i.29] from the EU commission.

Four C-ITS levels, named information, active safety, integral safety and passive safety phases, as shown in Figure 2 are recognized:

- The **"Information Phase"** covers normal driving conditions during which general information is provided to drivers or to the automated system. This corresponds to the normal data exchange, to be considered as part of the ITS related navigation systems and not further discussed in the present document.
- The **"Active Safety phase**" occurs during normal driving mode, when the driver and its C-ITS-system is informed or warned of events in their proximity. All applications as defined for Release 1 or as identified in the ETSI TR 102 492-1 [i.2] are C-ITS Active Safety related.
- The **"Integral Safety phase"** corresponds to the period in which the vehicle can intervene or take reversible preventive actions. This is the period before possible impact, in which Automation aspects have a key role and are seen as C-ITS Integral Safety.
- The "**Passive Safety phase"** comes at last in order to reduce the accident severity and includes the application of non-reversible countermeasures. When needed, this includes Rescue Facilities. This is an after-crash information exchange and is not considered in the present document, except for possibly (the application has not been defined yet) an E-CALL information exchange based on the C-ITS system.

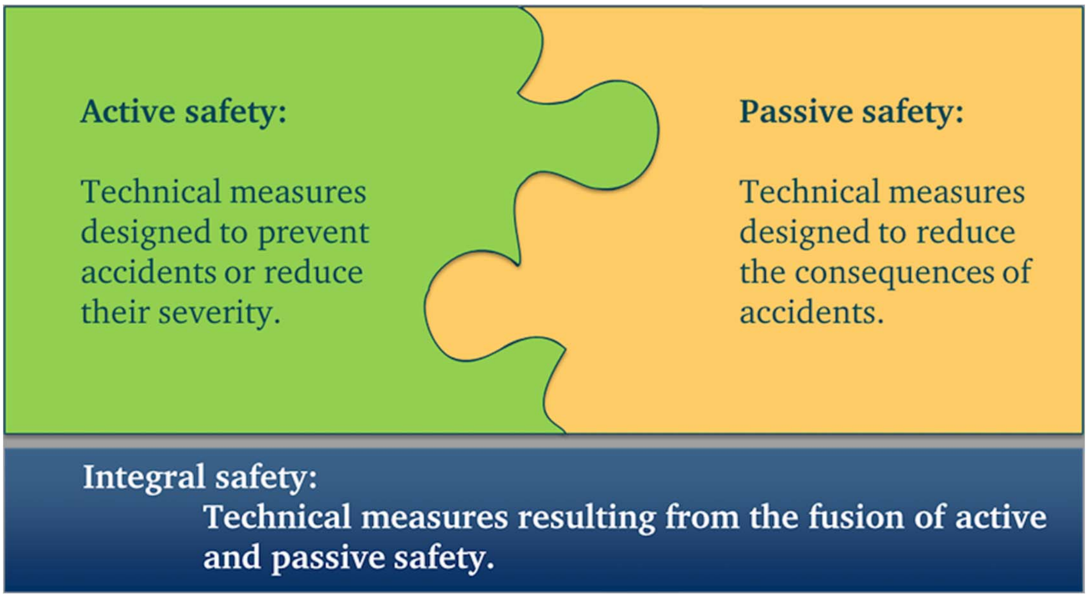

Figure 2: Phases of the vehicular safety system ([i.70])

In parallel with the innovation of C-ITS driver assistance applications, which are developing further in safety related vehicle Automation, road guidance (Informatization of traffic) is developing itself from static navigation towards lane level guidance and headway advice. These aspects are identified in the Declaration of Amsterdam [i.30] (see Figure 3) to lead to common insight and a single safety road traffic automation approach.

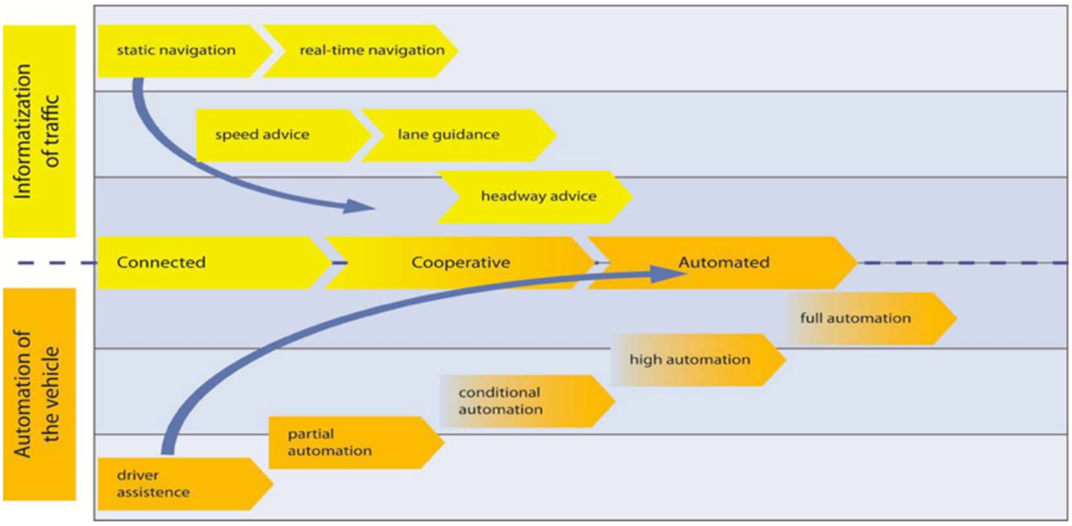

Figure 3: Merge of C-ITS and Vehicular Automation as agreed in the EU "Declaration of Amsterdam" [i.30]

Many innovative projects investigate beyond Release 1 applications. Just finished or currently active are for example: VRUITS [i.78], AutoNet [i.37], HIGHTS [i.76], TIMON [i.83], TransAID [i.57], RoadArt and there are new ones upcoming. There is quite a grow of applications and new possibilities are getting recognized. As a consequence, several application lists have been proposed.

Among the others, the project HIGHTS [i.76] has defined a list of C-ITS applications (see Table 2). This list was derived from the C-ITS platform phase I report [i.64], the Amsterdam Group [i.71], C2C-CC [i.45], ACEA [i.46], 5GAA [i.44], EATA [i.43] and the European projects C-ROADS [i.47], InterCor [i.48], CODEC [i.49] and country specific overviews.

Table 2: Safety related applications

Group	Use-Case
Road Works Warning (RWW)	Short Term Mobile; Short Term Static; Long Term Static; Driving RWW; Roadside RWW and Alarming Winter road works Vehicle
Traffic Flow	In Vehicle Signage Navigation; In Vehicle Signage Local; Dynamic Speed; Dynamic Sign Information; Network Flow Optimization; Shockwave Damping; Efficient traffic flow Urban/HighWay; Lane-Merge Assistance/Cooperative Merging; Complex Lane Marking; Regulatory/contextual speed limits notification; Traffic light optimal speed advisory; Zone access control for urban areas; Enhanced route guidance and navigation and Public Transport Vehicle Approaching
Intersections Specific	Energy Efficient Intersection user service; Green Light Optimal Speed Advice; Green Wave; Stopping Behaviour Optimization; Red Light Violation Warning; Cross-Traffic Left-Turn Assist, Intersection Movement Assist, Priority Request Business Transport; Priority Request Public Transport; Priority Request Emergency; Priority Request Group of Cyclists; Virtual VRI in Traffic centre and Intersection Obstacle indication
Vulnerable Road Users (VRU)	Bicycle Safety Awareness; Bicycle Priority; Bicycle Approaching Indication; Trian Awareness; Pedestrian Awareness; Motorcycle Awareness and Motorcycle Approaching Indication
Autonomous Driving	Basic ACC, Basic CACC; Advanced CACC; Basic Platooning; Advanced Platooning; Automation level 4 and 5 Vehicles; Coop. Adaptive Cruise Control; Merging Assistant; Speed Harmonisation; Automation level road assignment Static and Dynamic and Automation assist in Tunnels; Tele-operated Driving Support and Tele-operated driving for automated parking; Obstructed View Assist
Traffic Information	Virtual VMS and Traffic Information user service
Traffic Safety Avoidance	Traffic Jam Ahead Warning; Hazardous Location Warning; Emergency Vehicle Warning; Emergency Brake Light; Slow Vehicle Warning; Stationary Vehicle Warning; Overtaking Warning; Intention Sharing and Overtaking Assistance

Group	Use-Case
Incident Management	Automatic Incident Detection; Incident Warning
Navigation	Intermodal Route Planner; Navigation; Rerouting; Eco Route Planner; Laser scanner based landmark positioning Aid; Parking Assist; Point of interest notification; Automatic access control and parking access; ITS local electronic commerce; Media downloading; Multimodality support; Information on AFV fuelling & charging stations; Loading zone management and Fleet management
Vehicle Oriented Non-Safety	EV Charging Point Planner; Smart Parking Assistant; Pay How You Drive; Probe Vehicle Data and IMMA Interface
Vehicle Oriented Awareness	Behaviour (awareness); Road Status (awareness) holes in the road etc; Driver Status (awareness) and Vehicle Status (awareness); High-Definition Sensor Sharing; See Through for Passing
Tolling	Basic Road Tolling; REQ-2014-0431R03-Use_cases_of_Electronic_Toll_Collection (ETC)_service; ITS-G5 based Tolling and LTE based Tolling (user service)
E-Tachograph	E-Tachograph
Railway	Railway-Road Crossing
General Basic	The HIGHTS project [i.76] could be neutral place to develop some basic requirements on positioning and communication to fulfil the basic; Vehicle software/data provisioning and update; Functional testing new applications and Vehicle and RSU data calibration

Roadmaps from C2C-CC [i.45] and C-ROADs [i.47] roadmaps and the 5GAA [i.44] spectrum requirements paper identify the list of applications in Table 2 as the main applications which can be expected for an ITS Release 2. From this list, about 80 % of the applications benefit from safety related ad hoc, short-range active or integral safety information exchange. From the provided list, we can identify a number of key applications, which are expected to have a relative high impact on the safety spectrum usage. The order of this list is defined based on the matureness of the specifications and expected timing these applications may become operational.

- Extension of the Release 1 basic applications by the introduction of new warning applications and use of existing for automated driving leading to updates of CAM (ETSI EN 302 637-2 [i.6]), DENM (ETSI EN 302 637-3 [i.7]), SPATEM (ISO TS 19091 [i.10]), MAPEM (ISO TS 19091 [i.10]) and IVI (ISO TS 19321 [i.9]).

- Collective Perception (CP): Cooperative Awareness (CA), letting neighbours know the dynamic state of each C-ITS-S was a fundamental first step towards safety improvement, however for Integral Safety Awareness (ISA) more information, such as that including of non-C-ITS-connected road users will be required. The projects IMAGinE [i.36], ICT4CART [i.38] and TransAID [i.57] are projects which are realizing innovations in this field and there are some publications by C2C-CC [i.45] and ETSI TC ITS, all referring to the importance of having as much knowledge of the dynamic state of the surrounding, and therefore are referring to the work on Collective Perception as an important means, currently being developed by ETSI in the work program DTS/ITS-00167 (ETSI TS 103 324 [i.124]). The CPS is not triggered by a specific application and therefore at the generating side act as an application and triggers its own message generation as any general awareness message e.g. CAM, MAP. As the Collective Awareness Service (CAS) it acts as an application from the triggering perspective and as a service from the message generational perspective.

- Vulnerable Road Users (VRU): The project VRUITS [i.78] was one of the early EU projects with focus on VRU applications, remarking the importance of such application as VRUs are victims in many accidents. This project has been followed by many other initiatives leading to requirements gathered in the ETSI TR 103 300-1 [i.33], ETSI TS 103 300-2 [i.34] and ETSI TS 103 300-3 [i.35] specifications.

- Position augmentation: Indirectly, the above-mentioned applications require additional support by system services, which therefore need improvements. One of the crucial aspects is the support for position augmentation services. Augmentation services have been addressed in different EU projects such as HIGHTS [i.76], Propart [i.77], leading to standardization in the ETSI TS 103 301 [i.40] and ETSI EN 302 890-2 [i.41]. Augmentations entities as the CAS are awareness services and act as application from the triggering perspective.

- Manoeuver Coordination (MC): CCAD as part of CCAM [i.29] introduces automation use cases such as lane change and overtake. More of such use cases related to automation have been also recognized. Initial research such as executed in the AutoNet2030 [i.37] or TransAID [i.57] EU projects focusses on these aspects as well as projects further introduced in the coming years are expected to lead to standardizations such as currently being work on under the ETSI work programs DTS/ITS-00185 (ETSI TR 103 578 [i.125]) and DTS/ITS-00184 (ETSI TS 103 561 [i.127]).
- Manoeuvre Coordination Service (MCS) can include triggering conditions as well that it can be triggered by automation applications.
- Truck Platooning: Among the multiple platooning projects, an example is the EU project Ensemble [i.31], which is working on a first version of Platooning. In addition to several deliverables which are publicly available, at ETSI a study including the results of this and other projects is being currently being developed in ETSI TR 103 298 [i.126] and the related basic CACC specifications in ETSI TR 103 299 [i.32]. The Truck manufactures are expecting to use multiple ITS-G5 channels.
- Beside the identified safety related information exchange in previous points, there is additional information exchange required for a group of specific applications:
    - New intersection safety applications are being introduced by C-ROADS [i.47]. Applications realized in road infrastructure ICT systems to increase safety specifically based on infrastructure sensors. Additionally, applications such as weather forecast (short term, slippery road) and road conditions (sensors in/at the road and sensors in vehicles).
    - Traffic prioritization is a separate group of applications related to public transportation and emergency user services.
    - For agriculture additional specific applications are being defined by the agriculture organizations such as the AEF [i.39].
    - Urban rail requires information exchange between vehicles and the road infrastructure to satisfy urban rail specific safety requirements.
- Use cases such as high-definition sensor sharing, see through of passing that imply raw data exchange, e.g. video-frame exchange, require high bandwidth.
- New applications and new systems for non-safety-oriented user services such as software update services, vehicle health monitoring, security credentials and system validation need to be tested in life situations, while not interfering operating C-ITS-Ss.
- In case that information exchange makes use of multiple channels, the setup of use of the channels should be chosen as such that functional real time testing can still be facilitated allowing testing of all levels including new technologies.

The depicted main applications having impact are those also recognized in the C2C-CC paper "Multi-Channel Operation Functional Requirements" [i.115] and in the 5GAA paper "5GAA Releases White Paper on C-V2X Applications: Methodology, Examples and Service Level Requirements" [i.42] and "Study of spectrum needs for safety related intelligent transport systems day 1 and advanced Applications" [i.44]. Those applications which do not make use of ad-hoc communication are not here considered, as they do not have ad-hoc MCO communication requirements.

In the following clauses especially, these applications will be analysed for their MCO requirements.

5 Contextual aspects related to MCO

5.1 Introduction

To come to the realization of an implementable MCO concept not only system, functional and technical requirement but also pre-conditional aspects such as regulatory and general functional aspects need to be considered. In the following clauses, relevant MCO influencing aspects are recognized and consequences identified.

5.2 Influencing regulatorily aspects

5.2.1 Introduction

Regulations is country or regional dependent and therefore needs to be assessed. The following clauses handle relevant general and spectrum related regulatorily aspects to be considered for MCO.

5.2.2 European C-ITS regulatory aspects

5.2.2.1 Introduction

European regulation provides mandatory and optional obligations to C-ITS realization. This concerns not only direct functional or technical regulations but also general regulations such as those for open markets. In the following clauses those regulations are included which could have effect on the realization of an MCO concept and its requirements.

5.2.2.2 Technology neutrality

The European Regulation 2015/2120 [i.50] is laying down principles concerning open internet access, amending directive 2002/22/EC [i.51], Regulation No 531/2012 [i.52] and the EU antitrust and competition laws [i.53] on roaming on public mobile communication networks in the EU which needs to be considered. It states that any EU regulation needs to be "technology neutral" in order to ensure that EU regulation and related other legal EU directives or statements enable an open market according to antitrust and competition laws [i.53]. The term "technology neutrality" therefore needs to be judged at a regulatory level and does not directly imply technical neutrality at a technical level.

NOTE: In spectrum regulation, spectrum allocation can be technology specific such as for 3G/4G/5G. There the technology neutrality (open market) is realized by having auctions for the specific spectrum such that all can bid. For other pieces of the spectrum this can be assigned for a specific functional purpose or device group such as Radar, RLAN, Short-Range Device (SRD) and ITS bands. As none of the solutions is specified, they are "technology neutral"

At ETSI the technology neutrality is ensured by the ETSI Drafting Rules (EDRs) [i.97]. The standards are technically specific as it should be able to compare technical solutions for their compliance and or interoperability. Standards should not include implementation solutions other than example or as specific case. MCO specifications should follow the drafting rules, be technology agnostic and include functional and technical requirements to enable compliance and or interoperability.

Technology neutrality as stated in the EU regulations is in the first place a regulation to be followed while writing EU regulations and should be used as check in Business development processes.

5.2.2.3 C-ITS interoperability

The EU CCAM [i.29] refers to the European Directive 2010/40/EU [i.15] of the European Parliament and of the Council, which states in action (Article 3) that interoperability should be achieved, with the meaning "the capacity of systems and the underlaying business processes to exchange data and to share information and knowledge". About specifications, the Directive states that Europe should use C-ITS specifications which ensures compatibility, interoperability and continuity. Furthermore EU CCAM [i.29] refers to the EU COM(2016) 766 [i.54] regulation "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility", a regulation specific for C-ITS which identifies that interoperability has to be realized at all levels and interact with each other, across European borders and transport modes. C-ITS Interoperability should be effectively be reached following the principles reflected in Annex II of the European Directive 2010/40/EU [i.15].

As result the following Standardization definition is followed:

- C-ITS Interoperability is ensuring that C-ITS systems and the underlaying business process have the capability to exchange data and to share information and knowledge to enable the realization of tangible contribution towards solving key challenges affecting road transportation in Europe e.g. reducing congestion, lowering emissions, improving energy efficiency, attaining higher levels of safety and security including vulnerable road users, under the conditions it is proportionate, cost effective, supports continuity of user services, support C-ITS backward compatibility, promote quality of access, and respects operated C-ITS systems and coherence.

The EU COM (2016) 766 [i.54] regulation confirms this by stating that C-ITS interoperability needs to be reached at all levels as captured in this definition and in Annex II. The addition "interact with each other, across borders and transport modes" is already implicitly included in the here defined definition.

MCO concepts should not break the C-ITS interoperability.

5.2.2.4 C-ITS backward compatibility

The EU ITS regulation Directive 2010/40/EU [i.15] defined in article 4, compatibility as "the general ability of a device or system to work with another device or system without modification". This definition clearly only recognizes the backward related aspect. In the Annex II of the Directive 2010/40/EU [i.15], the ITS backward compatibility is identified as "ensuring, where appropriate, the capability for ITS systems to work with existing systems that share a common purpose, without hindering the development of new technologies". This provides some additional requirements which needs to be combined.

Based on these 2 identifications in the same regulation and including further consideration of the C-ITS methodology [i.64], the following C-ITS backward compatibility definition is a combination of the two descriptions specific for C-ITS:

- The general ability of newer versions of C-ITS and its C-ITS-Ss, to work with existing versions of C-ITS without modification ensuring, where appropriate, the correct operation of existing applications that share a common purpose, without hindering the development of new technologies.

MCO concepts for Release 2 and beyond should not break the C-ITS backward compatibility with previous releases, i.e. Release 1.

5.2.3 European C-ITS spectrum regulation

The legal basis of the operation of a C-ITS system in the frequency band 5 855 MHz to 5 925 MHz is the ECC Decision (08)01 [i.72] and the ECC recommendation (08)01 [i.73] including the EC implementation Decision C(2020)6773/F1 [i.74]. The overall spectrum is 70 MHz split into 7 channels of 10 MHz. The lower 2 channels from 5 855 MHz to 5 875 MHz are for traffic non-safety application whereas the band 5 875 MHz to 5 905 MHz is allocated to traffic safety applications. The lower two channels overlap with the SRD allocation in the band 5 725 MHz to 5 875 MHz (see Figure 4). In general, all existing 5 GHz RLAN channels can be used for safety ITS application, as depicted in Figure 4. In addition to the bands allocated in the band 63,72 GHz to 65,88 GHz has been allocated to ITS applications in ECC Decision (09)01 [i.94] and the EC Implementation Decision 2019/1345 [i.75]. The 64 GHz band will not be further considered in the present document.

In the updated regulation in 2020 an additional 20 MHz have been made available. The additional band is spit into a 10 MHz band fully available for safety regulation (5 905 MHz to 5 915 MHz) and a shared band between safety related road C-ITS and rail ITS (Urban Rail) (5 915 MHz to 5 925 MHz) where rail ITS has a priority. In Figure 5 the spectrum mask is depicted for a C-ITS system. The black line identifies the mask without mitigation and the green one with mitigation techniques to protect tolling operations in the band 5 795 MHz to 5 815 MHz.

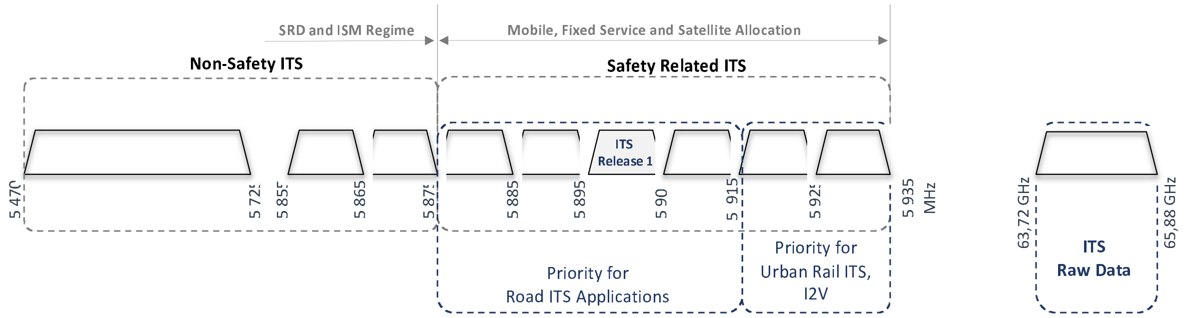

Figure 4: Regulated ITS spectrum [i.73], [i.72] and [i.75]

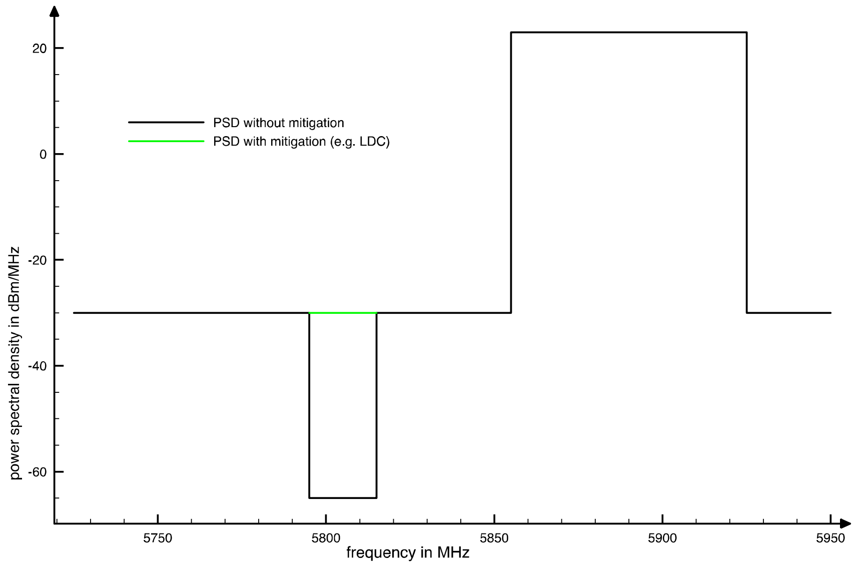

Figure 5: Regulatory spectrum mask in ECC Decision (08)01 [i.72] and ECC REC(08)01 [i.73] in the year 2020 in dBm/MHz E.I.R.P.

The maximum allowed TX Power Spectrum Density (PSD) is 23 dBm/MHz Equivalent Isotropic Radiated Power (EIRP) and maximum TX power of 33 dBm EIRP.

In the regulation the average duty cycle over 1 hour is assumed to have an average of 1 % [i.72] and a message length of 1 ms with a peak limitation to 3 % in 1 second. This allows for the transmission of typical messages like CAM on a regular pattern and some additional event driven emergency messages for a limited time (like DENM).

In the European spectrum regulation specific considerations and rules have been included to protect the proper operation of road tolling systems and Urban Rail system in the band 5 915 MHz to 5 925 MHz. The tolling system in the band 5 795 MHz to 5 815 MHz has to be protected by a significantly reduced spurious emission level of a C-ITS system in that band or equivalent mechanisms like the reduction of the duty cycle. The sharing mechanisms between Urban Rail systems in the band 5 915 MHz to 5 925 MHz are under development in ETSI. In this band the Urban Rail system has priority over any kind of road C-ITS system.

Since the band 5 855 MHz to 5 875 MHz is harmonised as part of the Short-Range Devices (SRD) Regulation EC Decision 2019/1345 [i.75] specific spectrum polite rules need to be implemented allowing other SRDs to access the spectrum. The ECC recommendation (08)01 [i.73] therefore identified this 20 MHz as 2 x 10 MHz ITS non-safety bands. For an ITS-G5 system these spectrum polite rules are inherently available by the CSMA/CA medium access protocol which uses a listen-before-talk mechanism with an energy threshold of -65 dBm. In the shared spectrum in the band 5 855 MHz to 5 975 MHz this mechanism allows for the smooth operation of other system in this licensed exempt band. Early analyses of whether this 20 MHz can be used for safety applications is depicted in Annex F and Annex G. These analyses show that under certain conditions these channels could be used for safety related information exchange. Further studies are needed to identify these conditions.

In the band 5 875 MHz to 5 925 MHz C-ITS systems are operated on a co-primary allocation together with fixed satellite uplinks. These uplinks are operated at very limited number of positions in Europe. In the very close vicinity of these satellite base stations operating in the band 5 875 MHz to 5 925 MHz a range degradation of the C-ITS systems might occur. More detailed investigations (simulations, measurements) are needed in the future to evaluate the effect in real life situations.

In Europe the CEPT has allocated the frequency band 63,72 to 65,88 GHz for safety related and traffic efficiency ITS applications in ECC Decision (09)01 [i.94] from 5 July 2019. In this allocation ITS is considered as part of the mobile user services. In this 2,16 GHz of spectrum ITS devices can operate with a maximum EIRP of 40 dBm. No PSD limits are defined in the decision.

The band is also harmonised in the EC Decision 2019/1343 [i.75] from 2 August 2019 as band number 77 of the SRD decision using the same conditions.

The band has to be shared with other applications, which are mainly used by fixed links and broadband SRDs. The band can be used for future extensions of the ITS user services with the main focus onto very short-range high data-rate communication. An initial specification effort is under way as part of the IEEE 802.11bd [i.104] activities.

In the scope of the MCO development covered in the present document the 63,72 to 65,88 GHz spectrum band will not be further considered. However, MCO should not be limited to only handle 10 MHz channels, as the 63,72 to 65,88 GHz spectrum regulation ECC Decision (09)01 [i.94] wider channels could be addressed. Although only 10 MHz channels are being used, wider channels may be important in the future. Therefore, any MCO concept should allow the use of various channel bandwidths in future.

5.3 Functional needs

Release 1, ETSI TR 101 607 [i.25] standards have been realized, implemented and are operationally setting the initial C-ITS business case by making use of a single 10 MHz safety related channel in the 5,9 GHz band. Next releases need to be C-ITS backward compatible with existing Release 1 and allow differentiation in an open market as required by EU antitrust and competition laws [i.53]. Release 2 C-ITS standards should allow the implementation of Release 2 applications based on the extension of the existing Release 1 requirements. Additional releases thereafter will have to enable further innovation as open as possible and always be C-ITS backward compatible with all previous releases.

An MCO concept should therefore support the realization of extensions and changes as much as possible so that C-ITS backward compatibility can be maintained, and that new applications or functions can be introduced as evolutions of the previous ones. In line with that, Release 2 should be a superset of Release 1.

In practice, an MCO concept should be an extension of the communication architecture of the single channel concept as specified in Release 1. The MCO concept should support the realization of implementations in an open, competition challenging market where all stakeholders can make their own choices and are only bound to specifications where C-ITS Interoperability is required. It should allow stakeholders to realize single, dual and multi-channel implementations not limited to current spectrum regulation.

Therefore, it is also important to take the applications requirements as starting point to come to an MCO concept. It is also a requirement that the MCO concept fulfils C-ITS interoperability, as defined in clause 5.2.2.4, only at those levels where this is explicitly needed.

5.4 Security needs according to the EU C-ITS certification and security policies

The EU commission has defined security and certification policies [i.56]. The security policies [i.56] are of influence on the C-ITS security requirements. MCO functionalities in the C-ITS-S are internal station functions and therefore not affected by security requirements. Security requirements are of influence on the message exchange and MCO functions may therefore be indirectly affected when they need to handle secured data. The effect of security and privacy regulations needs to be assessed when defining each of the MCO functions.

5.5 Release 1 Basic Set of Application (BSA) release consequences

5.5.1 Introduction

According to European regulations and arguments presented in previous clauses such as in clause 5.3 for the realization of a MCO concept the Release 1 set of specifications needs to be the starting point. Release 1 includes all Basic Set of Applications (BSA) identified in the ETSI TR 102 638 [i.4] but also covers initial In-Vehicle Signage (IVS) applications supported by message standard IVI (ISO TS 19321 [i.9]) and Traffic light priority applications supported by message standards SPATEM/MAPEM (ISO TS 19091 [i.10] and SAE J2735 [i.81] as supported by the C2C-CC Basic System Profile (BSP) [i.45], ETSI LTE-V2X Profile ETSI TS 103 723 [i.110] and the C-ROADs profiles [i.47]. The following clauses reflect the communication behaviour of this message exchange as identified in many European Projects and stakeholder consortia evaluations. The evaluations consider only the information exchange for these applications in the single 10 MHz band (180) in the safety related 5,9 GHz spectrum.

5.5.2 C-ITS in the ITS Architecture

The ITS architecture as defined in ETSI EN 302 665 [i.8] allows the realization of many ITS ECO-systems. Any of these ITS ECO-systems need to comply to EU antitrust and competition laws and therefore are technology neutral. C-ITS applications resemble a subset of ITS applications and are considered as a separate C-ITS ECO-System with its own specific trust-domain and C-ITS specific interoperability requirements as defined in clause 5.2.2.3. Functionally, C-ITS ECO system related solutions make use of a subset of the ITS architecture possibilities and have mostly specific requirements related to safety only partly covered in the ETSI EN 302 665 [i.8].

In an ITS one application could be realized within the constraints of one ECO-system while another application could be realized within the constraints of another ECO-System. Of cause an application can also realize a use case or use cases making use of several ECO-systems. An example of the last is for instance a road operator application which provides sign information via Hybrid Communication through IP protocols in one ECO-system to Service Providers (SPs) or end users and in parallel via Ad-hoc networking in the C-ITS ECO-system to other end users. In this case a road operator receiving information from within more than one ECO-system (stakeholder groups) should make sure that it does not conflict with privacy requirements and related security as they may differ from one to another C-ITS ECO-System because of different trust conditions agreed in those ECO-Systems. ECO-Systems could also differ with regards to the communication principles. For instance, one EC-System could be based on Internet like communication handshaking principles including using unique IP addressing methods, while another ECO-System such as the C-ITS ECO-System can be based on Ad-hoc broadcasting methods not knowing the IP address including tailored privacy and security mechanism. Bringing data from one ECO-System to one other ECO-Systems needs to be carefully handled and agreed among all affected stakeholders.

5.5.3 User services, applications, use cases, scenarios and services

The terms user service, application, use case, scenario, situation and service (facilities layer service) relate to one another but the terms are used in a mixed manor in standardization. This mixed use is illustrated in the ITS architecture specification ETSI EN 302 665 [i.8] which includes the following phrase: "The ITS-S applications making use of the ITS-S services to connect to one or more other ITS-S applications. An association of two or more complementary ITS-S applications constitutes an ITS application which provides an ITS service to a user of ITS". In this phrase the term service is used in the context of a user (functional) and of a facilities layer service (technical), something when used in the same document can lead to misunderstanding. Similar observations were made for scenario and use case and their relation to applications and services. In the MCO context, these terms are defined as follows (see Figure 1):

- **A Situation** is a description of relevant scenery (everything presents within a static snapshot, including the functional actors and physical situation at a given moment) considering (driving) functions related goals and values. Including dynamic elements, scenery and self-representation.

- **A Scenario** describes temporal development in a sequence of situations (e.g. initial and after situations) based on events and actions (story line). Chronological sequence of a set of scenes, including sequence of actions and events and goals and intentions of actors get apparent.

- **A Use case** description is a function description including the desired behaviour (of the expecting system and the actors) specification including definition of one or more supported scenarios.

- **A User service** is the service provided by an implemented application to users e.g. humans or systems.
- **An Application** is the technical implementation of the supported use case(s) residing at the Application layer in the ITS Architecture. Applications could also provide information which can be used by other applications. A facilities layer message service which includes message generation triggering rules and from which the message generation is not primary triggered by other applications, such as most awareness services, is conceptually considered to be an application for its triggering part and a service for its message generational part.
- **A Service** is a technical service residing at the facilities layer in the ITS architecture, which provides technical services to applications and other facilities services.

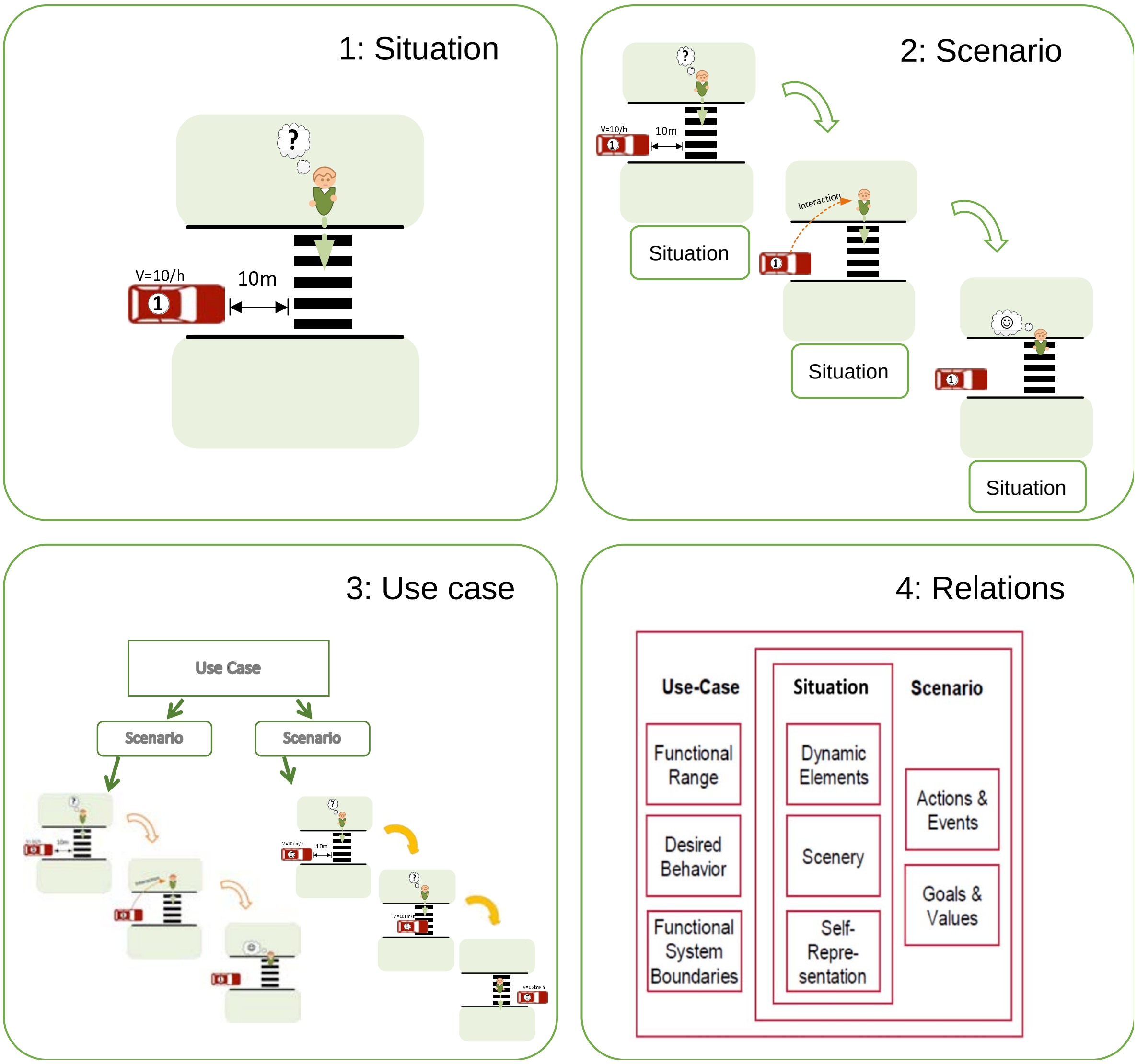

Figure 6: Scene, scenario, use case and their relations

5.5.4 Message generation in the system

A use case is a functional description, it includes scenarios and their scenes and is realized by an application. A C-ITS application can realize one or more C-ITS safety or non-safety related use cases (Figure 7) and can trigger different message services at the same time to support a specific scene.

In clause 5.5.3, Figure 6 shows the different scenes in which timely, step by step decisions are made and where communication takes place between the road users. Each scenario introduces a series of events each with the possible requirements of sending some messages. Depending on the dynamics of the situation, the use case requirements lead to the situation that the application triggers the generation of series of messages related to the dynamics of the situation.

Applications can consist of a generating part operating in one C-ITS-S and a consuming part operating in another C-ITS-S. Application could also only consist of a consuming part making use of information provided by other applications or awareness services, see Figure 8.

An application is responsible for the realization of the use case and therefore responsible for triggering the message generation. The messages generation is the core responsibility of the message services. As it can be recognized from Figure 8 there are also services such as CAM and CPM which besides generating the message also trigger the message generation. Conceptually such awareness services realize one or more use cases by themselves and act simultaneously as an application and as a message service. Specifically, such awareness services behave as information providers to many other applications and implement one or more use cases, mostly while not being triggered by other applications. For instance, the CAS specification ETSI EN 302 637-2 [i.6] includes triggering rules, while the CAS resides technically at the facilities layer.

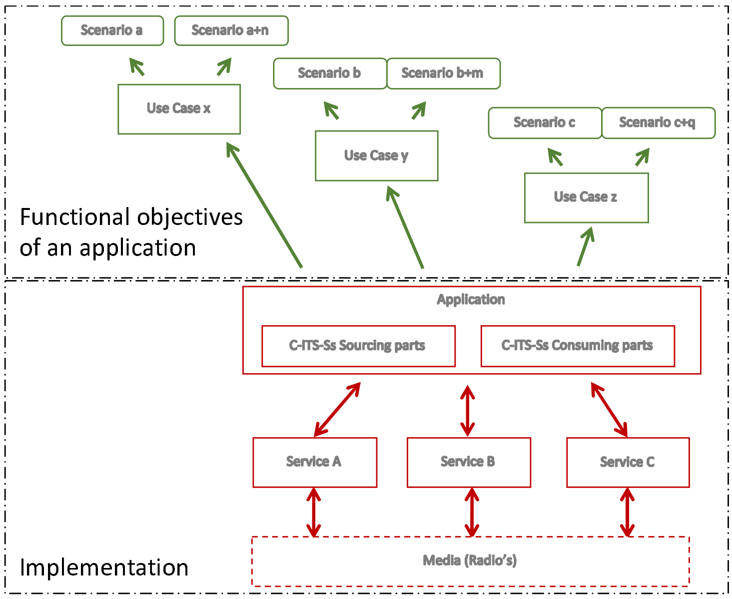

Figure 7: C-ITS application realizing use cases

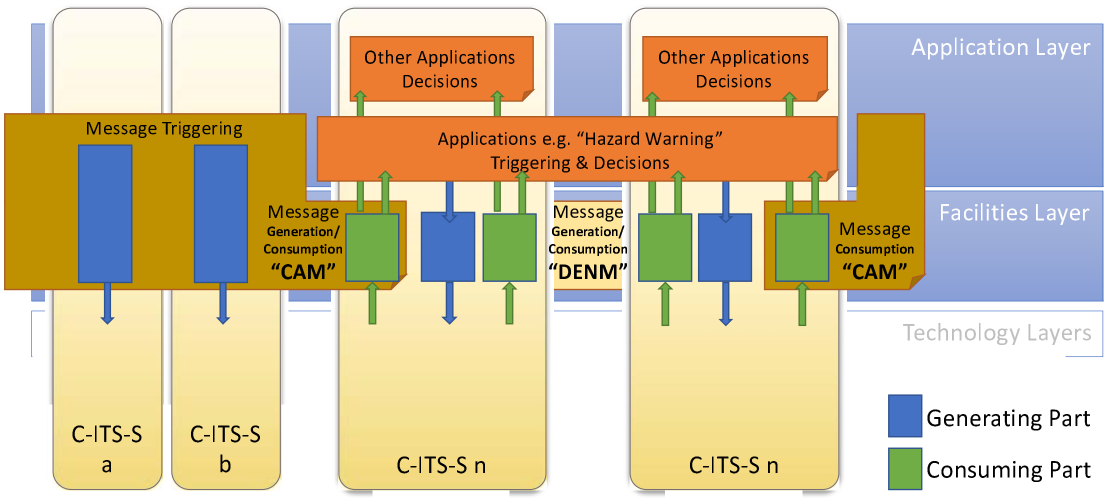

Figure 8: C-ITS application partitioning into generating and consuming parts in the various C-ITS-Ss

For the realization of Release 1 user services in a Release 1 single channel implementation there was no need for any channel resource management mechanism among different applications. Now that more and more applications are being introduced (see clauses 4 and 6) and the realization of all these applications and awareness services require the use multiple channels, the transmission of various messages over multiple channels need to be managed to ensure predictable and robust operation for all applications. It is not sufficient to let the applications just to trigger the message services as successful transmission can't be guaranteed based on unknown possible use by others. Applications should be made aware about whether and under what conditions successful transmission can be guaranteed. Applications should be notified about the transmission capabilities.

As identified only the applications are aware of the behaviour of their supported use case and can't be aware of the behaviour of other applications. Therefore, supporting entities are needed which can keep an overview of the communication requirements of all applications, statically and dynamically as well as being aware of the capabilities of the underlaying communications while managing the message dataflow.

Figure 9 (for Release 1 applications) and Figure 10 (for Release 2 applications) recognize the entities for a Release 2 system. In the management plane there should be an MCO_CROSS management entity entity and as part of the facilities layer in the data plane there should be an message dataflow MCO_FAC entity which is further explained in clause 9.4.9.

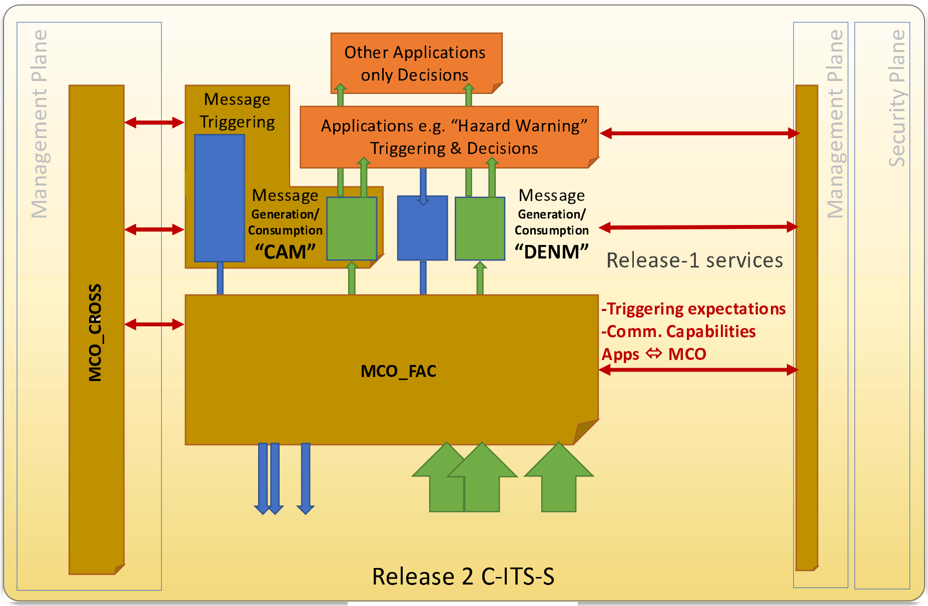

Figure 9: Message triggering from out of Release 1 application or awareness service in a Release 2 system

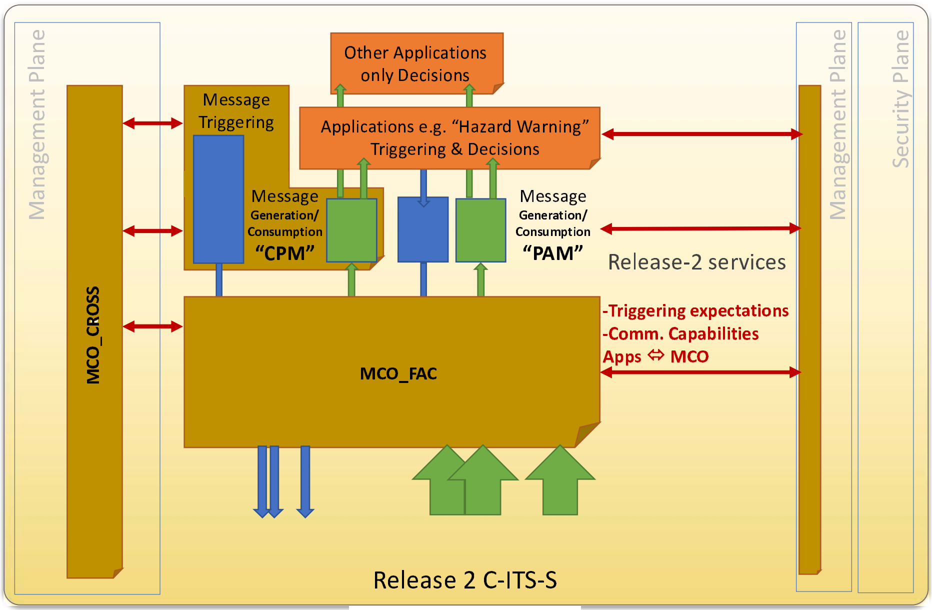

Figure 10: Message triggering from out of application or awareness service Release 2

NOTE: When implementing backward compatible Release 1 functionalities in a Release 2 compliant multi-channel supporting C-ITS-S, the implementer needs to consider that Release 1 applications need to report their needs to the MCO entities about their communication requirements.

5.5.5 BSA communication considerations

The Basis set of Applications (BSA) as specified in ETSI TR 102 638 [i.4] was the starting point of many functional and technical developments and evaluations in Europe. Car industry-oriented projects such as sim^{TD} [i.13] and generally-oriented EU projects such as CVIS [i.11] and Safespot [i.12] were important to allow different stakeholders to work together and realize interoperable standards and specifications. All applications defined in ETSI TR 102 638 [i.4] were based on two basic C-ITS facilities services, i.e. the Cooperative Awareness and the Decentralized Environmental Notifications services with the message types CAM [i.6] and DENM [i.7], respectively.

The basic operation of these message sets in the single 10 MHz channel in the 5,9 GHz safety related spectrum was identified and led to the specification of a set of communication parameters, system conditions, standards and white papers. All communication settings are depicted from released standards and made interoperable in the first ETSI ITS Release 1 ETSI ETSI TR 101 607 [i.25] and C2C-CC Basic System Profile (BSP) [i.45], and ETSI LTE-V2X Profile ETSI TS 103 723 [i.110].

For the purpose of creating an MCO concept, the following Release 1 aspects need to be considered:

- Release 1 identified communication parameters are based on expected C-ITS penetration in the coming 5-10 years of about 60-70 % (mainly CAMs and DENMs) market penetration level. For higher penetration levels a single channel for the Release 1 services supported Release 1 applications supporting use cases it may not be sufficient.

- Current single channel congestion control mechanisms intend to keep headroom to enable the transmission of high priority messages. For example, a restrictive congestion level is conservatively set to 60 % when T_{on} is max 1 ms in ETSI TS 102 687 [i.86], and more CR limits are set to higher priority (i.e. PPPP) messages in ETSI TS 103 574 [i.20].

- It is further assumed that DENMs are rarely transmitted so that CAM transmissions dominantly use the channel. These aspects were confirmed by large-scale tests at that time.

- Later as proposed by authorities based on simulations and expectations the transmission in the same service channel of IVI, SPATEM and MAPEM was agreed under the condition that the size and transmission frequencies will stay low, and that the transmission priority should be lower than CAM and DENM. These aspects have not been verified on large-scale but assumed not to be problem during the initial years of deployment.

If the C-ITS penetration reaches near 100 %, CAMs and even DENMs will possibly not all be successfully transmitted, and therefore off-loading or other mitigation mechanisms may need to be considered.

5.6 Release 1 specifications being affected

5.6.1 Introduction

Different Release 1 specifications can influence the design of an MCO concept. They will need to be taken into account and evolved when needed.

5.6.2 Traffic classes

The transmission of packets triggered by applications are classified into Traffic Classes (TC) at the Facilities layer depending on their priority. The TC is included in a field of the Common Header of all transmitted GeoNetworking packets as specified in the ETSI EN 302 636-4-1 [i.87]. The Common Header is defined within the media-independent functionalities, which are common to all C-ITS access technologies for short-range wireless communication to be used for GeoNetworking. The TC field has 8 bits that include:

- TC ID (6 bits): as specified in the media-dependent part of GeoNetworking corresponding to the interface over which the packet will be transmitted, e.g. in ETSI TS 102 636-4-2 [i.88] for ITS-G5 and ETSI TS 102 636-4-3 [i.89] for LTE-V2X.
- Channel *Offload* (1 bit): indicates whether the packet may be off-loaded to another channel than the one specified in the TC ID.
- SCF (store-carry-forward, 1 bit): indicates whether the packet should be buffered when no suitable neighbour exists.

According to the C2C-CC Basic System Profile 1.5.1 [i.45], it is not required to off-load packets to another channel, and therefore the Channel Off-load bit of the TC field is set to *pGnChannelOffLoad*=0. It is intended to enable future use of according features and could be particularly useful in a potential MCO concept.

In ITS-G5, each TC ID is mapped into an Access Category (AC). ACs are used by ITS-G5 to prioritize between different types of packets using the four different Enhanced Distributed Channel Access (EDCA) queue defined in ETSI EN 302 663 [i.22] for each frequency channel. ITS-G5 is able to prioritize between different ACs using different listening periods, Arbitration InterFrame Space (AIFS) and Contention Window (CW) settings for each AC [i.22]. The TC IDs are also mapped into transmission parameters for ITS-G5, such as the maximum transmission power or the data rate (modulation and coding scheme) [i.22].

In LTE-V2X, each TC ID is mapped into a ProSe Per-Packet Priority (PPPP) [i.89]. Packets are prioritized according to its PPPP value in LTE-V2X as defined in ETSI TS 136 331 [i.98] and ETSI TS 136 213 [i.99]. Each PPPP is mapped to certain transmission parameters, such as modulation and coding scheme. Higher priority PPPPs can use a higher amount of radio resources, as defined in ETSI TS 103 574 [i.20], following the congestion control mechanism defined for LTE-V2X.

The MCO concept should be able to differentiate the message triggering priority of the different applications. For example, packet generated triggered by high priority applications could be transmitted in one channel, where more C-ITS-Ss may be listening to, while lower priority applications message triggered transmissions could be off-loaded to another channel. This could be done by reusing the already existing TCs or extending them for a more granular and accurate classification.

5.6.3 Channel usage

For ITS-G5, ETSI TS 102 724 [i.85] specifies the channel usage in the ITS G5A and ITS G5B bands for multichannel operation support, including control and service channels operation for ITS G5, ITS G5 transmit and receive policies, channel selection and configuration, and ITS G5 adjacent channel interference considerations, among others. According to ETSI TS 102 724 [i.85], the Channel-Configuration entity located at the Access layer manages the transmission to and reception from multiple channels. The usage of the ITS-G5 channels is under control of the DCC. ETSI TS 102 724 [i.85]defines the access layer requirements for different DCC profiles (DP1 to DP32) for each channel. The message received by the access layer will be transmitted using the first possible channel in the usage order defined in ETSI TS 102 724 [i.85] depending on the congestion status and the DCC profile of the message.

While ETSI TS 102 724 [i.85] is an active specification, the adoption and current usage of the DCC profiles and the multichannel operation concept defined in ETSI TS 102 724 [i.85] are not clear:

- DPs were adopted and mapped to TCs in the C2C-CC Basic System Profile 1.2.0 (September 2017), but their definition and usage are not present in the current version, 1.5.1 (July 2020) [i.45].
- Current C2C-CC Basic System Profile [i.45] includes in requirement RS_BSP_435 that the access layer should be compliant with ETSI TS 102 724 [i.85], but it might refer to the channel policies.
- The access layer requirements defined in ETSI TS 102 724 [i.85] for the different DCC profiles are not compliant with the DCC Adaptive strategy defined in ETSI EN 302 637-2 [i.6]. These requirements are restricted to 3 states of the DCC Reactive strategy, but the ETSI EN 302 637-2 [i.6] leaves the door open to have more states when the Reactive strategy is used.
- ETSI TS 102 724 [i.85] is referred by ETSI EN 302 637-2 [i.6] for the adaptation of the $T_{\_GenCam\_Dcc}$ parameter in order to reduce the CAM generation according to the channel usage requirements of DCC. It can be misleading as it gives the impression that the 32 DPs should be enforced.
- The access layer requirements defined in ETSI TS 102 724 [i.85] for the different DCC profiles collide with possible message transmission policies for a possible DCC Facilities entity and DCC Facilities entity's handling of services, for example, CAM, CPM in terms of their respective T_GenCam, T_GenCpm, T_offmin, etc. has to be made clear.

A revision of ETSI TS 102 724 [i.85] might be needed in consideration of potential problems regarding congestion control with MCO.

5.7 Functional safety and safety of the intended functionality

5.7.1 Introduction

The overall safety of a system or piece of equipment depends on the automatic protection operating correctly in response to its inputs or possible failure in a predictable manner (fail-safe). The automatic protection system should be designed to properly handle like human errors, hardware failures and operational/environmental stress. When implementing functions which may have a safety impact, there are two safety aspects of a system or piece of equipment that need to be considered. In different industries but especially in the Automotive industries, Functional Safety standardized by ISO TS 26262 [i.90] and Safety Of The Intended Functionality as (SOTIF), ISO PAS 21448 [i.93] are considered basic requirements and therefore also have to be considered here. So far, such systems have been based on equipment internal operations only. In case information was used for equipment internal decisions those were never safety related. In C-ITS Release 1 applications this is the case. In Release 1, the applications are only awareness and warning related. Beyond Release 1, Basic Safety Applications (BSA) include automated decision making and as these have safety impact these need to satisfy Functional Safety and SOTIF requirements. Therefore, when for these automation related decisions information is used which is received from other equipment, the hole chain, including the communication needs to be assessed for its Functional Safety and SOTIF impact. In the following clauses these two aspects are assessed.

5.7.2 Impact of Safety Of The Intended Functionality (SOTIF)

The ISO/PAS 21448 [i.93]: Road Vehicles - Safety Of The Intended Functionality (SOTIF), applies to functionalities that require proper situational awareness in order to be safe. The standard is concerned with guaranteeing safety of the intended functionality in the absence of a fault. This is in contrast with traditional functional safety, which is concerned with mitigating risk due to system failure. SOTIF provides guidance on design, verification, and validation measures. Applying these measures helps you achieve safety in situations without failure.

ISO/PAS 21448 [i.93] applies to systems such as emergency intervention systems and advanced driver assistance systems. These systems could have safety hazards without system failure and therefore may also require some consideration.

Automated systems have huge volumes of data - and that data is fed to complex algorithms. AI and machine learning are critical for developing these systems. To avoid potential safety hazards, AI will need to make decisions. This includes scenarios that require situational awareness. Using ISO PAS 21448 [i.93] will be key to ensure that AI is able to make decisions and avoid safety hazards.

SOTIF applies to safety violations that occur without the failure of a system. As an example, when the road is icy, an AI-based system might be unable to comprehend the situation and respond properly. This impacts the vehicle's ability to operate safely. Without sensing the icy road condition, a self-driving vehicle might drive at a faster speed than is safe for the condition of the road would allow. Fulfilling ISO PAS 21448 [i.93] means taking that situation into account and making decisions based on probability.

The goal of SOTIF is to reduce potential unknown and unsafe conditions. However, this goal is very broad and it is difficult to show that one has accounted for all potential edge cases. SOTIF has influence on the Functional Safety application requirements and need to be assessed in a common SOTIF-Functional Safety process use case by use case.

As SOTIF analyses have direct influence on the Functional Safety (FS) related requirements and that any MCO concept needs to support a never exactly known amount of use cases, only clear Functional Safety levels requirements can be considered. SOTIF use case related requirements should further have effect on the implementation itself and no further effect on MCO specifications.

5.7.3 Functional safety

The Functional safety standards ISO 26262 [i.90] applies to existing, established systems, such as Dynamic Stability Control (DSC) systems or airbags. For these systems, safety is ensured by mitigating the risk of system failure. Functional safety is a known requirement within the vehicle industry. The ISO 26262 [i.90] is an extensive set of Functional Safety for Road Vehicle standards. These specifications are tailored to systems in a box configuration, systems where a single stakeholder can be responsible for a single solution. Approximate cross-domain mapping of Automotive Safety Integrity Level (ASIL) can be found in Table 3.

Table 3: Approximate cross-domain mapping of ASIL as defined in [i.115]

Domain	Domain-Specific Safety Levels				
Automotive (ISO 26262)	QM	ASIL-A	ASIL-B/C	ASIL-D	-
General (IEC-61508)	-	SIL-1	SIL-2	SIL-3	SIL-4
Aviation (ED-12/DO-178/DO-254)	DAL-E	DAL-D	DAL-C	DAL-B	DAL-A
Railway (CENELEC 50126/128/129)	-	SIL-1	SIL-2	SIL-3	SIL-4

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ASIL is a risk classification scheme defined by the ISO 26262 standard [i.90]. This is an adaptation of the Safety Integrity Level used in IEC 61508 [i.91] for the automotive industry. This classification helps defining the safety requirements necessary to be in line with the ISO 26262 standard [i.90]. The ASIL is established by performing a risk analysis of a potential hazard by looking at the Severity, Exposure and Controllability of the vehicle operating scenarios. The safety goal for that hazard in turn carries the ASIL requirements.

There are five ASILs identified by the standard: ASIL QM, ASIL A, ASIL B, ASIL C, and ASIL D. ASIL A dictates the lowest integrity requirements on the product having implementation impact while ASIL D the highest (ISO 26262 standard [i.90]). Hazards that are identified as QM do not dictate any safety requirements.

For instance, ASIL D needs to be applied for avoiding an unreasonable residual risk (see ISO 26262-3:2011 [i.92], Part 3: Concept phase). In particular, ASIL D represents likely potential for severely life-threatening or fatal injury in the event of a malfunction and requires the highest level of assurance that the dependent safety goals are sufficient and have been achieved (see ISO 26262-3:2011 [i.92] (Concept phase)).

From the perspective of the vehicle system, shared C-ITS information is seen as external information. From a functional safety perspective, this means that the system to evaluate is extended to external parts (parts of other equipment), something which is not yet considered in any functional safety standard and therefore need to be evaluated at use case, function, system and implementation.

For instance, an automatic emergency brake system can relay 100 % on V2X Information, which results in an ASIL B level requirement, while a system that uses sensor fusion with radar sensor information may end up in requiring an ASIL QM for V2X. Another example is that an emergency brake system covering the full speed range of a car is ASIL C while a system for low speeds < 30 km/h is ASIL QM. Generalizing the functional safety requirement so far has not been succeeded.

Functional Safety Requirements (FSRs) for communication systems are often expressed in reception probability requirements or information availability requirements. Requirements often realized by introducing redundancy in the communication system. An important indicator is the "Fault Tolerance Time" (FTT), which is the maximum time that the system stays safe even if the communication is not working any more. Retransmission on the same channel helps in functions with long FTT, as long as we disregard denial-of-service attacks. Redundant transmissions on different bands helps in almost all functions and situations. As this brings additional costs this needs to be justified with detailed hazard analysis and decomposition to have arguments to create dual band communication.

Satisfying FSRs can be realized by functional layer solutions as well as or in combination with technical layers solutions. As for communications the FFT is seen as the main important indicator identifying the possible need for retransmission on the same, other channel or even in other spectrum as possible measures to support FSRs from a communication perspective. The requirement for a C-ITS-S will depend on the ASIL level to be supported and its FFT. As the real requirements are not known for higher ASIL levels then QM at the moment and MCO concept should support at least this QM level and enable higher ASIL level extensions as much as possible. Specific use case and scenario related requirements are seen as implementation specific and may be included in the application requirements as identified in clause 6.

ASIL QM level is the lowest ASIL but is still safety related and therefore although message reception can't be guaranteed fully for radio communication, the predictability should be better than best effort as used for standard non-safety related message exchange. The application and awareness service message exchange should not be interfered by non-safety related applications or influenced by other application or awareness service message exchange in the C-ITS Eco-System to ensure the correct operation of each of the applications or services.

6 Functional MCO considerations and potential requirements

6.1 Introduction

In the following clauses the application communication potential requirements are identified from the most spectrum demanding applications and triggering awareness services as identified in Table 2.

6.2 Release 1 extended user services

6.2.1 Introduction

In clause 5.5.5, the single channel requirements of the Release 1 applications are addressed. As identified in 5GAA [i.44], C2C-CC [i.45] and C-ROADs [i.47] reports (see clause 4.2) for Release 2, extended warning use cases and their applications are identified and recognized requiring more effective use of the existing message sets such as DENM (ETSI EN 302 637-3 [i.7]), SPATEM (ISO TS 19091 [i.10]), MAPEM (ISO TS 19091 [i.10]) and IVI (ISO TS 19321 [i.9]), but also extension of these sets. In the following clauses the related extensions and MCO communication requirements identified.

6.2.2 Extended message dissemination

The increase of events message triggering safety applications, extended data characterization and higher accuracy requirement will increase the size and amount of the DENM (ETSI EN 302 637-3 [i.7]), SPATEM (ISO TS 19091 [i.10]), MAPEM (ISO TS 19091 [i.10]) and IVI (ISO TS 19321 [i.9]). One example is the MAPEM (ISO TS 19091 [i.10]), currently being a single layer map will grow significantly into a multi-layer and more dynamic map. In general, the extended use of warning applications more towards automated actions in vehicles for example will lead only to more precise parameters such as the position accuracy and a like. This could also have effect on the transmission rules and require higher levels of trust and confidence. All of this will lead to more data transmissions while penetration of the amount of C-ITS-Ss is expected to grow. These aspects are currently being investigated but have not result in any change of specifications and no test results are available.

6.2.3 MCO communication requirements

Based on the ongoing investigations into extended warning user services, the message dissemination requirements are expected to increase. The size and the number of transmitted messages will increase and this may lead to a situation, in which the congestion state in the single channel is reached earlier. For such cases it could be required to use off-load mechanisms in order to satisfy the application requirements.

6.3 System MCO relevant aspects

6.3.1 Introduction

In order to allow applications to exchange information, they need to be supported by some additional system facilities layer services beyond the message services. The minimum set would at least consist of security as this is needed to realize trust among the different equipment participating in C-ITS. Additionally, the C-ITS includes possibilities to use services such as the Service Announcement (SA) service as defined in the ETSI EN 302 890-1 [i.58], which enables the possibility of making C-ITS-Ss aware of available C-ITS user services. Also, the Position and Time (PoTi) service as defined in the ETSI EN 302 890-2 [i.41] which includes the support for position accuracy improvement services making use of information exchange. This also include privacy considerations.

In the following clauses those system services which require information exchange between C-ITS-Ss are identified.

6.3.2 Service Announcement (SA)

6.3.2.1 Introduction

The Service Announcement Service (SAS) is a service to inform users of the availability of a specific location-based user service. A C-ITS-S can send a Service Announcement Essential Message (SAEM) as specified in the ETSI EN 302 890-1 [i.58]. The ETSI EN 302 890-1 [i.58] supports C-ITS safety and non-safety user services and can lead to communication via any protocol or network, whether this is via hybrid communication as defined in the C-ITS platform phase I report [i.64], via multiple technologies or via various channels in a single technology setup, ad-hoc communication, via DAB+, or via internet protocols. The SAS generates an awareness type message (SAEM) enabling C-ITS applications to select the appropriate communication setup suited for the application. The Service Announcement Service (SAS) as specified in the ETSI EN 302 890-1 [i.58] has a direct link to the base SAS standards ISO TS 16460 [i.59] and ISO TS 22418 [i.60].

6.3.2.2 SAEM information dissemination

A SAEM is application specific and can be disseminated outside of the service relevance area to prepare the consuming part of the application. These messages could also be planned to be along a predictable journey. The SAEM should include all necessary information for the C-ITS to allow its applications to setup the communications such that the information to satisfy the application can be received. SPs and C-ITS-Ss applications can announce their applications or capabilities via SAEM unicast or broadcast transmissions.

Currently, the SAEM includes information about how and where application specific information can be exchanged. From a protocol point of view the ETSI EN 302 890-1 [i.58] supports WAVE [i.26] Short Message Protocol, GeoNetworking, Basic Transport Protocol, and IPv6 (based on TCP according to IEEE 1609.3-2016 [i.61]).

In case BTP is used, the BTP port number should be as specified in ETSI TS 103 248 [i.62]. The SAEM should be send as broadcast with a repetition between 0 and 255 (number of times the SAEM is transmitted per 5 s). Other protocols or repetition intervals information should be specified for MCO based on the access technology and the channel, considering whether the user service is safety related or non-safety related.

User services can be categorized in two classes. User services could address all users or a specific user group in which a user group can be categorized as requiring a specific membership based on which a member is aware of the existence and operation of the related application.

In case it concerns being a member of a specific group the SP could chose to send the SAEM on any channel as long as all members know where it can be received.

In case it concerns a general user service a general agreement is needed how and where all C-ITS users can have access to any offered general user service. To allow all participating C-ITS-Ss to be aware of advertised user service whether it is for safety related or non-safety purposes, the SAEMs should be distributed on a predefined channel known by all participating C-ITS-Ss.

6.3.2.3 SAEM MCO communication requirements

Selection of the channel to use could be made depending on the level of congestion and availability of the channels to support load balancing (see clause 9.3.2) mechanisms for example. Further considerations are identified in clause 6.3.2.2. The communication requirements are given by Table 4.

Table 4: SAS communication requirements as defined [i.115]

Service Announcement			
Requirements	Messages	SAM	Comment
Transmission Rate		1 Hz	
Transmission dynamics		Low	
Area of relevance urban		150m	
Area of relevance rural roads		150m	
Area of relevance rural highways		500m	
Message Size		400 Bytes	
Message Latency, According to Current		SAM	
Message Validity			Currently not defined
Message Priority			Currently not defined
Transmission mode		Multicast	
Transmission type		Non-repeditive	
Urban network message channel load		<2%	
Rural roads network message channel load		<2%	
Highway network message channel load		<2%	
V2V		-	
I2V and V2I		X	
V2E and E2V		-	
Reception Propability Requirement		Standard	
Security requirements		C-ITS	
Liability Impact		NO	
Functional Safety Requirements (FSR)		QM	These are annoucements and not part of the actual application and thereforee will always be the lowest level
SOTIF		NO	See FSR
Position Accuracy level A		Standard	

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NOTE 2: % channel load is the allocated % of the channel load where 100 % represents the maximum channel load before the channel congestion state is reached. There are no messages and therefor assumed similar to CAM.

6.3.3 Position Accuracy Improvement (PAI)

6.3.3.1 Introduction

Most C-ITS application are location-based services and depend on having knowledge about time and position. For the realization of Cooperative Intelligent Transportation Systems in principle any time and positioning technology could be selected; however, given the nature of the application area (cooperative ITS), a commonly defined representation of time and position is required. For Release 1 C-ITS applications, GNSS was chosen as reference and by that their coordination system was selected. Depending on the location of an ITS-S, such as whether this is fixed or moving around, the performance might change as a consequence of a different access to GNSS satellites. In open field this is simpler than in urban areas, mountains, and forests, where this could be much more difficult. In some places such as tunnels and in buildings (parking) this is even impossible. As a result, the position accuracy depends on the accuracy of the GNSS system and the environment the ITS-S is currently being active in.

Analyses done in Europe showed average variations between 1-7 meter. The 7-meter accuracy is in urban areas (worse case was having no accuracy; a statistical worse case of 13-meter was determined) where you would like to have a much better accuracy then in open field (highway). Release 1 applications result in basic generic warnings and awareness information exchange, for which current GNSS capabilities are sufficient. This is not expected in Release 2 applications, where VRU and automation user services, for instance, have extended position accuracy requirements of better than < 25 cm. GNSS will develop further and higher accuracies also enabled by Galileo improvement can be seen, however it is not foreseen that this < 25 cm can be realized in those scenarios for the foreseeable future. Therefore, to realize the interested use cases by means of their applications, additional methods such as augmentation methods are required. There are many methods possible, also including those relying on specific technologies. As the object here is the realization of an MCO concept, the focus is limited to those that need information exchange to achieve the required PAI.

As PAI functionalities are supporting C-ITS functionalities, these are implemented as awareness services operating as self-containing entity in the facilities layer and act as application to satisfy the use case and generates the messages as message service. PAI can be realized by a single or combined set of Position Augmentation Services (PASs). Different types depending on different methods are known. For a few of these PASs the exchange of information between ITS-Ss is essential. The ETSI EN 302 890-2 [i.41] includes the way such services can be used and includes the description of two of such methods. One is fully included and the other references to the Infrastructure protocol specification ETSI TS 103 301 [i.40].

In the ETSI EN 302 890-2 [i.41] the Roadside Ranging augmentation Service (RRS) is specified, and for differential mode there is the GNSS Positioning Correction (GPC) augmentation service based on RTK as identified in the ETSI TS 103 301 [i.40] resulting in GNSS Correction Message (GCM) exchange also referencing to ETSI TS 103 301 [i.40].

6.3.3.2 PAI information Dissemination

GNSS differential mode is a known augmentation method and is defined in different standards such as RTCM 1005, 1077, 1087, 1097 [i.95]. It is based on providing additional information via ground stations. This could be RSUs but also cellular base stations. The ETSI EN 302 890-2 [i.41] and ETSI TS 103 301 [i.40] specify how to implement it in an ITS-S. For the distribution of the RTK, the RSUs broadcast the related information for the use in a area up to 5 000 meters.

The RRS is a triangulation-based method requiring RSUs not to be in a straight line, which is foreseen as an issue for use on highways. It therefore is more usable in urban environments, where also the additional accuracy is required. Both Infrastructure and Vehicle ITS-Ss (V-ITS-Ss) are actively participating in the application. Because the RSU just sends back a MAC acknowledgement, it depends on the CAM security that a vehicle trusts the RSUs. So, the RRM unicast should be sent without Security header by the vehicle. The RRM messages are short, but the effect of contention window is not negligible (take up almost same time for the unicast + ACK as the data transmission itself). It is recommended to limit the transmission rate as specified in the ETSI EN 302 890-2 [i.41] where is stated: "A V-ITS-S should transmit no more than 1 probe frame in any 1 sec period to a Roadside ITS-S (R-ITS-S)" while not using a security header.

With regards to channel use, the PA services could be considered as not safety related as they do not direct have effect on safety situations themselves. However, as they could be essential for the operation of specific safety related applications such as VRU applications, they could instead be considered still as safety related.

6.3.3.3 PAI MCO communication requirements

Although there are also other augmentation methods in this context, in Table 5 only the communication requirements specified in the PoTi specification ETSI EN 302 890-2 [i.41] are considered.

Table 5: PAI communication requirements as described in [i.115]

GNSS Positioning Correction (GCM) & Roadside Ranging Augmentation (RRM)			
Requirements **Messages**	**GCM**	**RRM**	**Comment**
Transmission Rate (RTCM 1077+1087+1097)	1*3 Hz	Typical 9~12 Hz, Max'20Hz.	GCM: 1 Hz each for three payload types. The GCM service announcement (RTCM 1005) is also 1 Hz, but much shorter message type. RRM: Max 20 Hz but will vary from 3~12Hz. Typically like CAM generation rules (range measurements will align with vehicle dynamics). There is a max limit of 20Hz as per EN 302 571, so even if the application is going to request 60Hz the DCC is going to drop the packets (and limit it to 20Hz). Which RSUs to range to and how much to range is left as a differentation feature for product developers. The standards sets the max limits only (which is the same as curent EN 302 571 and later will be capped by the usage rate of a car to be specified as less than 3% in the new EN 302 571).
Transmission dynamics	Average	Not	The GCM message has a length variation (see the message size information below), while the RRM has fixed size.
Area of relevance urban	1000 m	300 m	Multi-hop broadcast can be used in GCM case, and single-hop unicast in RRM case
Area of relevance rural roads	+/- 5000 m	700 m	Estimation: half-distance between roadside units. RRM: used in Tunnels.
Area of relevance rural highways	+/- 1000 m	1000 m	Estimation: half-distance between roadside units. RRM: not applicable because there will be no triangulation possibility along one line.
Message Size	200 - 1100 Byte	32 Bytes	Estimation includes 96 bytes security header for GCM (400 everage). RRM messages are short, but effect of Contention Window size must be included. (20 bytes data + Contention Window size). RRM: Fixed sized packet, MAC layer data frame with zero length. PHY MCS r-1/2 16QAM assumed and should be used (64 us on air time). Total Data-Ack is around 160us (per range measurement).
Message validity			Currently not defined
Message Priotiy			Currently not defined
Transmission mode	Broadcast	Unicast	
Transmission type	Repetitive	Repeats (as CAM)	
Urban network message channel load	<2.5%	<100%	Based on 6 mb/s channel capacity. GCM: 3*1 Hz rate for RTCM 1077+1087+1097, 6 rebroadcasts from various directions. RRM: In a typical deployment around 200~250 vehicles will use this service with a channel load of 40~50%.
Rural roads network message channel load	<1%	<25%	Based on 6 mb/s channel capacity. GCM: 3*1 Hz rate for RTCM 1077+1087+1097, 2 rebroadcasts from the two directions. RRM: 0.1% (only in tunnels where this serive will be typically used). Only range to 1 or 2 R-ITS.
Highway network message channel load	<1%	<.0%	
V2V	-	X	
I2V and V2I	X	Yes	
V2E and E2V	-	X	
Reception Probability Requirement	Standard	Standard	Transmission rate is sufficiently high for packet loss to be tolerated.
Security requirements	C-ITS	C-ITS	Main risk is spoofed position data by fake RSU.
Liability Impact	No	No	Low - Augmentation service -- requires other sensors for integrity check
Functional Safety Requirements	ASIL QM	ASIL QM	As this is not part of the safety information exchange it self but an indirect parameter only through the confidence level there is influence.
SOTIF	No	No	See FSR

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6.3.4 Privacy

The EU General Data Protection Regulation (GDPR) [i.55] handles the protection of natural persons in relation to the processing of personal data as a fundamental right. The regulation Article 8(1) of the Charter of Fundamental Rights of the European Union (the 'Charter') and Article 16(1) of the Treaty on the Functioning of the European Union (TFEU) state that everyone has the right to the protection of their personal data.

The GDPR handles about information/data shared by whatever system this is realized. The GDPR sets requirements related to the ownership and privacy of data exchanged and looks at this functionally. When looking at the OSI model it focusses on facilities and application entities which can have influence on the processing of shared data.

MCO concepts could be considered being of influence in the process of sharing data but have no role in the data handling process itself. In the MCO definition process, only a check needs to be performed whether there are privacy risks to be considered. It is not expected to have a big impact on the MCO concept.

The EC conducted in 2016 a study [i.64] regarding privacy. In this study only CAM and DENM were identified and a single communication channel was considered. In 2017, the "C-ITS platform Phase II" report [i.65] identified tracking as a risk and certificate change as a mitigation technique. The document states: "The working group is of the opinion that further mitigation measures concerning the possibility of tracking should be taken, such as analysing how static data in CAM can be used on their own or in combination with other information to identify a single vehicle as well as analysing any appropriate type of _do-not-track_ functions, as well as encryption". This has to be considered when changing the communication channel, so that a tracking between different channels should not be possible.

ETSI TR 103 415 [i.66] considered the pseudonym change only on a single communication channel. This is also the case for the current version of the ETSI TS 102 941 [i.67]. The latter only considers a separate channel for the pseudonym updates and not for normal applications. According to deliverable D3.3 of project iKoPA [i.68], five risk factors have to be considered:

- Identifiers should be changeable: the change of identifiers should be possible on any communication channel and technology before starting a new transmission.
- All identifiers of a single stack need to be changed in coordination: the linking of identifiers can only be prevented, when all change at the same time on all layers. This includes MAC-addresses, session identifiers, IP-addresses, pseudonyms, etc.
- Multi-stack applications need to coordinate identifier changes across stacks: if the communication is related to different technologies, or on different channels for the same technology, the identifiers for all related layers and technologies have to change at the same time.
- Pseudo-identifiers in the data content maybe enabled: pseudo-identifiers are identifiers that are indirectly related to the C-ITS-S. Example are an TCP-port of a connection, or the time and coordinates of a message.
- Identity beacons: communication technologies like Bluetooth, or WLAN send periodic information about the own station to announce their presences. This is also true for C-ITS-S sending beacons, if no other message is sent during some time. It is currently not clear if this is necessary for all channels.

Release 2 applications are expected to have some automated functions, for instance that based on the information received the vehicle will execute an automated break. Such applications need to be supported with more trust and more privacy requirements. In the first place these requirements have effect on an MCO concept, however as they result in additional security and privacy mechanism, they need to be supported by the MCO concept. Therefore a detailed analysis of the privacy impact on the security mechanism for MCO is necessary. But this is out of scope of the present document.

Further privacy requirements could lead to additional requirements in most cases translated in the security requirements. So far, no MCO communication related requirements are foreseen.

Two essential privacy requirements regarding security and message handling are mentioned here for informative purpose only:

- The usage of more than one channel or more than one technology should not lead to additional possibilities to identify or track the C-ITS-S (user).
- Sending the same message on different channels or technologies should not lead to additional possibilities to identify or track the C-ITS-S (user).

6.3.5 Security

6.3.5.1 Introduction

The security reference architecture (ETSI TS 102 940 [i.80]) and the specified application are independent of the technology and the channel usage. The security information is included in the standard messages and does not have additional MCO requirements. Any way security has MCO requirements related to the certificate update information exchange.

Not specifically due to the introduction of MCO but more of the introduction of more active applications there are 2 threats to consider.

- The more C-ITS applications there are active in a C-ITS station the more this could lead to recognition of the station and therefore may act as an identifier which may lead to a privacy issue (ETSI TS 102 940, clause 4.3.1.1 [i.80]).
- The security requirements regarding authentication and authorization are not changed through MCO. Confidentiality and privacy (see also the clause 6.3.4) could introduce additional complexity if different certificates and identifiers are used on different channels which needs to be considered.

6.3.5.2 Security information dissemination

To allow the security system to operate, certificates are needed. These certificates can be hardcoded in the C-ITS-S but they are most often downloaded to have the flexibility to update them. In case the certificate updating is enabled through ad-hoc networks, this should be handled by a Certificate Updating Service (CUS) which is not yet defined. Similar to the PAI service it satisfies a specific use case and is seen as an awareness service. The communication from an authorization authority to the C-ITS equipment is in most cases handled through more than one type of communications. One between the authorization authority and an RSU C-ITS-S which could be wired or cellular and from the RSU C-ITS-S to other C-ITS-Ss through ad-hoc communication.

Such ad-hoc communication may be realized via agreed direct communication in a single fixed channel, but it can also be realized through a non-fixed approach making use of the Service Announcement mechanism. In the last case the service could be moved to any available channel, media or technology.

Although the certificates are being used by safety services, the certificate exchange itself may be considered as non-safety and therefore needs to be shared on a non-safety channel.

Experiments within Scoop@F [i.14] of sharing certificates by Ad-hoc networks have been done but no final specification was created.

6.3.5.3 Security MCO communication requirements

For MCO however the following capability requirements can be identified:

- In case Ad-hoc communication is used for the exchange of certificates, these are exchanged on an EU harmonised channel or assigned through the SAEM mechanism. the use of a SAEM mechanism is most flexible as authorities can chose where the user service is available and therefore the SAEM method is preferred. Regional alignment on which channels could be used are still required.
- As in the Scoop@F [i.14] project which realized C-ITS user services based on ITS-G5 it was assumed that certificate exchange would not happen in the basic service channel according to C2C-CC BSP SCH0 and that this exchange is not safety related by itself. Certificate Update Messages (CUMs) exchange should be realized in a non-safety related channel.
- An Interface between the MCO entities and the security entities in the security layer could be necessary for the handling e.g. security associations, replay protection, plausibility validation, certificates and identity management.

Table 6 provides the expected communication requirements supporting the CUS.

Table 6: CUS communication requirements as described in [i.115]

Certificates update			Comment
Requirements / Messages	SAM	CUM	
Transmission Rate	1 Hz	-	
Transmission dynamics	Low	Low	
Area of relevance urban	200 m	200 m	
Area of relevance rural roads	200 m	200 m	
Area of relevance rural highways	200 m	200 m	
Message Size	300 Bytes	2000	
Message Latency, According to Current	SAM	?	
Message validity			Currently not defined
Message prioriti			Currently not defined
Transmission mode	Multicast	Multicast	
Transmission type	Repeditive	Bulk	
Urban network message channel load	<2%	<2%	
Rural roads network message channel load	<2%	<2%	
Highway network message channel load	<2%	<2%	
V2V	-	-	
I2V and V2I	X	X	
V2E and E2V	-	-	
Reception Propability Requirement	Standard	Standard	
Security requirements	C-ITS	C-ITS	
Liability Impact	NO	NO	
Functional Safety Requirements	ASIL QM	ASIL QM	These are suupporting services not critical for safety
SOTIF	NO	NO	See FSR

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6.4 Collective Perception (CP)

6.4.1 Introduction

The Cooperative Awareness Service (CA Service) is an awareness service which is not triggered by an application but has its own triggering rules to inform other C-ITS-Ss about the dynamic state of itself enabling many applications in the receiving C-ITS-Ss to improve safety for the user. This was the first step bringing awareness. It has been recognized that Integral Safety Awareness (ISA) applications require more accurate and additional information.

Collective Perception Message (CPM) is an awareness service with a similar behaviour having also its own triggering conditions. It provides information of objects based on detection by sensor systems such as cameras and infra-red sensors connected to the C-ITS-S. The projects IMAGinE [i.36], ICT4CART [i.38] and TransAID [i.57] are realizing innovations in this field which are reflected in the technical report ETSI TR 103 562 [i.16] which outlines the potential functional possibilities and as currently being developed by ETSI in the work program DTS/ITS-00167 (ETSI TS 103 324 [i.124]), the Collective Perception (CP) service. The CP service supports sharing the kinematic and attitude state information about objects in the surrounding of the C-ITS-S equipped road user. These objects for instance could be C-ITS-S non-equipped road users, static or other dynamic objects like roadblocks and Empty Road Segments (ERSs). These can be detected by local perception sensors such as cameras and infrared sensors.

6.4.2 CP information dissemination

Collective Perception (CP) will further increase awareness and may address the following use cases:

- Create Awareness about **non-connected road users** of any kind which could be subdivided in:
  - Non-connected vehicles.
  - Non-connected other road users (mainly VRUs)
    Which could be still differently behaving, e.g. bikes, moppets, pedestrians, and road workers.
- Create Awareness about **Detected Safety-Critical Objects** (DSCOs): these objects are not a recognized as active road users but can be seen as object influencing road situations and related resulting traffic behaviour.
- Create Awareness via **CAM Information Aggregation** (CIA): CAMs received from connected road users which are possibly not received by other connected road users due to radio propagation of the surrounding environment can be aggregated in a CPM.

- Create Awareness about **Empty Road Segments** (ERSs): provide recognized areas which are not occupied by any of the known objects as referenced in previous categories.

While the CAS describes only the behaviour of a single road user and so supports a single use case, the CPS provides information about the dynamic state of different behaving objects. Current specification identifies the rate being dominated by the object with most dynamic behaviour and information for those with a lower dynamic state, the information is less frequently included in the message.

The analysis in the ETSI TR 103 562 [i.16] show that when CPS is realized as a single awareness service implementing all above mentioned use cases by means of a singular message transmission approach (all in a single channel), the CPS awareness service could require more than a single channel to operate. Instead of supporting all use cases by means of a single message transmission approach, it is therefore advised to separate the the messages for each of the use cases. By means of using a use case classification as listed below, for each of the classes separate message transmission rules could be made applicable including transmission on different channels. The following CPM use case classification is identified:

- Non-Connected Vehicles (NC-Veh, Extension of the vehicle awareness as shared by CAM)
- Non-Connected Vulnerable Road Users (NC-VRU, VRUs, a new use case implemented in VRU applications)
- Detected Safety-Critical Objects and ERSs (DSCOs+ERSs, additional information)
- CAM information Aggregation (special case on request of authorities, such as CIA and RSU initiatives)

The CPM is generated cyclically with a message size that depends on the number of detected objects and onboard sensors, among other parameters as currently being developed by ETSI in the work program DTS/ITS-00167 (ETSI TS 103 324 [i.124]). CP messages can be fragmented when exceeding the maximum message size allowed by the lower layers, and each segment can be interpreted independently. Adaptive message generation rates are used to decrease the channel load while focusing on reporting changes in the dynamic road environment. How often a detected object is included in a CPM depends on the mobility of the object. The maximum message generation rate may be limited by the congestion state of the channel.

Simulation results in [i.17] show that CPM generation rates between 3 Hz and 10 Hz, and CPM sizes between 300 bytes and 1 350 bytes can be expected. The CP message lifetime does not exceed 1s. The Traffic Class (TC) of the CPM is defined in ETSI EN 302 636-4-1 [i.87]. CPMs are signed using private keys associated to Authorization Tickets that contain SSPs of type BitmapSsp as specified in ETSI TS 103 097 [i.63].

The CPM brings additional awareness beyond the CAM as part of Release 2 and therefore are seen as extension of the CAM awareness. For Release 2, CPM transmission should therefore be handled at the same Functional Safety QM level as CAM.

6.4.3 CP MCO communication requirements

The size of the CPM very much depends on the scenario e.g. urban, sub urban or highway and whether there is dense traffic including pedestrians or not.

CPMs are generated periodically with a rate controlled by the CP service in the originating ITS-S. The generation frequency is determined by taking into account the dynamic behaviour of the detected object status, e.g. change of position, speed or direction, sending of CPMs for the same (perceived) object by another ITS-S.

Depending on the type of C-ITS-S, the CPM could be limited to a specific object class as currently being developed by ETSI in the work program DTS/ITS-00167 (ETSI TS 103 324 [i.124]).

The size variation is very dynamic depending on the scenario, see Table 8 and the dynamic state perceived from the different detected objects. The studies presented in ETSI TR 103 562 [i.16] indicate that CPM transmission requires message segmentation (larger size then allowed by the underlaying used technologies) and is expected to exceed the bandwidth of a single channel in future.

The minimum time elapsed between the start of consecutive CPM generation events should be equal to or larger than *T_GenCpm*. *T_GenCpm* is limited to $T\_GenCpmMin \leq T\_GenCpm \leq T\_GenCpmMax$, where *T_GenCpmMin* and *T_GenCpmMax* are defined in Table 7.

In case of ITS-G5, *T_GenCpm* will be managed according to the channel usage requirements of Decentralized Congestion Control (DCC) as specified in ETSI TS 102 724 [i.85]. The parameter *T_GenCpm* will be provided by the management entity in the unit of milliseconds. If the management entity provides this parameter with a value above *T_GenCpmMax*, *T_GenCpm* will be set to *T_GenCpmMax* and if the value is below *T_GenCpmMin* or if this parameter is not provided, the *T_GenCpm* will be set to *T_GenCpmMin*. The parameter *T_GenCpm* represents the currently valid lower limit for the time elapsed between consecutive CPM generation events.

In case of LTE-V2X PC5, *T_GenCpm* will be managed in accordance to the congestion control mechanism defined by the access layer as specified in ETSI TS 103 574 [i.20].

Table 7: Expected Parameters for CPM generation

Parameter	Type	Meaning	Recommended value
T_GenCpmMin	Time in ms	The minimum time elapsed between the start of consecutive CPM generation events. For LFC [2 000] ms should be used (Optional Container added as part of the CPM every 2 000 ms).	100
T_GenCpmMax	Time in ms	The maximum time elapsed between the start of consecutive CPM generation events.	1 000

Table 8: Typical CPM requirements as described in [i.115]

Collective Perception Classes		Non-Connected	Non-Connected Others				Detected	CAM		
	Objects	Vehicles	Bikes/Mopeds	Pedestrians	Road Workers	Disabled	Objects	Aggregation	Emty Segments	
Requirements	Message	CPM-V	CPM-B	CPM-P	CPM-W	CPM-D	CPM-D	CPM-A	CPM-E	Comment
Transmission Rate		1-10Hz	1-10Hz	1-10Hz	1-10Hz	1-10Hz	1-10Hz	1-10Hz	1-10Hz	A single ITS-S will only send one CPM containing all sensed and relevant objects within the set limits
Transmission dynamics		depends on speed of objects and own speed as well as protection level (e.g. high for VRU), CPM Tx rates can rapidly change								one CPM message can contain all listed object types
Area of relevance urban		>150m	>150m	>150m	>150m	>150m	>150m	>150m	>150m	
Area of relevance suburban		>150m	>150m	>150m	>150m	>150m	>150m	>150m	>150m	
Area of relevance highways		>500m	-	-	>500m	-	>500m	>500m	>500m	
Message Size Urban		CPM 1000 - 1900 Byte; one CPM contains all sensed objects and package size Message size changes depending on number of detected objects, including vehicles, pedestrians, cyclists, all seen by the in-vehicle-perception sensors such as cameras and radars. including security certificate.								
Message Size Rural roads										
Message Size highways										
Message Latency, According to Current		CPM	CPM	CPM	CPM	CPM	CPM	CPM	CPM	
Message validity										Currently not defined
Message prioirty										Currently not defined
Transmission mode		Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	
Transmission type		Repetitive	Repetitive	Repetitive	Repetitive	Repetitive	Repetitive	Repetitive	Repetitive	
Urban network message channel load		see C2C-CC position paper on "Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving"								
Rural roads network message channel load										
Highway network message channel load										
V2V		X	X	X	X	X	X		X	
I2V and V2I		X	X	X	X	X	X	X	X	
V2E and E2V										
Reception Propability Requirement		Same Release 1	Same Release 1	Same Release 1	Same Release 1	Same Release 1	Same Release 1	Same Release 1	Same Release 1	
Security requirements		C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	
Liability Impact		NO	NO	NO	NO	NO	NO	NO	NO	
Functional Safety Requirements		ASIL QM	ASIL QM	ASIL QM	ASIL QM	ASIL QM	ASIL QM	ASIL QM	ASIL QM	For the moment only QM others levels may be supported later
SOTIF		NO	NO	NO	NO	NO	NO	NO	NO	Refer to FSR
Position Accuracy level A		Same Release 1	Target <0.5m Minimum same as Release 1]	Target <0.5m Minimum same as Release 1]	Target <0.5m Minimum same as Release 1]	Target <0.5m Minimum same as Release 1]	Same Release 1	Same Release 1	Same Release 1	

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6.5 Vulnerable Road User (VRU)

6.5.1 Introduction

The project VRUITS [i.78] was one of the early EU projects with focus on VRU applications, pointing out the importance of such application as VRUs are victims in many of road accidents. This project has been followed by many other initiatives from which a diverse number of VRU awareness use cases are included in the ETSI TR 103 300-1 [i.33].

For the realization of VRU awareness by other road users a number of aspects is relevant from which two are essential to realize a high enough confidence level such that the information is used.

- The position accuracy according to the HIGHTS project [i.76] needs to be better than 30 cm to be able to identify the difference of the different VRUs and whether it is on the road or on the sidewalk.
- The determination of the active state (participating in traffic or not) and its intentions.

Overcoming these challenges depends on availability of high position accuracy. GNSS positioning sub-systems by their own are currently not able to provide this high position accuracy and further improvement has to come from other sub-systems. Determination whether an VRU is participating in traffic or not depends in the first place on this position accuracy and depends on how to identify the VRU intentions.

There are three cases by which a C-ITS-S can be informed about the presents of an VRU.

- By its own sensors.
- By an observing ITS-S which recognizes the presence of an VRU and informs other ITS-Ss.
- By the ITS-S of the VRU.

The first case is obvious. In the second case, for instance, an RSU can be the observer and provide VRU information via the CPM as described in clause 6.4. In the last case, VRU Awareness messages (VAMs) can be transmitted by the VRU C-ITS-S as identified in ETSI TS 103 300-2 [i.34] and specified in ETSI TS 103 300-3 [i.35].

6.5.2 VRU information dissemination

The objective of the VRU basic service is to enable the transmission and reception of VRU Awareness Messages (VAMs) to enhance the protection of road users such as pedestrians, bicyclists, motorcyclists as well as animals that may pose a safety risk to other road users.

VRUs like other road users should only transmit safety related information in case it participates in the road traffic. VRU ITS-S should always send VAMs, while other ITS-S including infrastructure and vehicle ITS-S can use CPM to signal the identified presence of a VRU in the vicinity. The relevant use cases are depicted in ETSI TR 103 300-1 [i.33].

The following VRU profiles are specified in clause 6.1 of ETSI TS 103 300-2 [i.34]:

- VRU Profile 1 - Pedestrian. Typical VRUs in this profile: pedestrians, i.e. road users not using a mechanical device for their trip. It includes for example pedestrians on a pavement, but also children, prams, disabled persons, blind persons guided by a dog, elderly persons, persons walking beside their bicycle.
- VRU Profile 2 - Bicyclist. Typical VRUs in this profile: bicyclist and similar e.g. light vehicles riders, possibly with an electric engine. It includes bicyclists, but also wheelchair users, horses carrying a rider, skaters, e-scooters, personal transporter, etc.
- VRU Profile 3 - Motorcyclist. Typical VRUs in this profile: motorcyclists, which are equipped with engines that allow them to move on the road. It includes users (driver and passengers, e.g. children and animals) of Powered Two Wheelers (PTW) such as mopeds (motorized scooters), motorcycles or sidecars.
- VRU Profile 4 - Animals presenting a safety risk to other road users. Typical VRUs in this profile: dogs, wild animals, horses, cows, sheep, etc. Some of these VRUs might have their own ITS-S (e.g. dog in a city or a horse) but most of the VRUs in this profile will only be indirectly detected. Especially wild animals in rural areas and highway situations.

NOTE: A VRU vehicle itself does not represent a VRU but only the combination with at least one person will create the VRU.

The details of the VRU awareness basic service for enabling VAM-based enhancement of VRU protection are specified in ETSI TS 103 300-3 [i.35].

6.5.3 VRU communication requirements

In case VRUs participate in traffic and are integral part of road safety focussed improvements, the use cases given in ETSI TR 103 300-1 [i.33] and the functional requirements given in ETSI TS 103 300-2 [i.34] apply.

Based on the specified VBS operation and the given VAM format in ETSI TS 103 300-3 [i.35] communication and resource requirements can be derived. As all C-ITS messages the VAM dissemination is managed in accordance with the relevant congestion control mechanisms depending on the used access layer.

The size of an individual VAM message depends on the actual situation, the set of parameters to be transmitted and the use of security certificates and signatures. Some typical VAM sizes for VRU profile 1 are given in Table 9.

Parameters:

- High Frequency Container (HFC):
  - Heading, speed, longitudinal acceleration, lane position, environment
- Low Frequency Container (LFC):
  - Profile, size class, but not exterior lights
- Motion Prediction Container:
  - Path History (PH): 1, 5, 10 entries
  - Path prediction (PD): 5 entries

Table 9: Some typical VAM sizes for VRU profile 1

Case No	Parameter	Comment	Size
1	LFC + 10PH + 5PD	HFC including LFC and 10 points in the path history without GN header	137 bytes
2	No LFC + 10PH + 5PD	HFC, no LFC and 10 points in the path history without GN header	135 bytes
3	LFC + 5PH + 5PD	HFC including LFC and 5 points in the path history without GN header	104 bytes
4	No LFC + 5PH + 5PD	HFC no LFC and 5 points in the path history without GN header	103 bytes
5	LFC + 1PH + 5PD	HFC including LFC and 1 point in the path history without GN header	78 bytes
6	No LFC + 1PH + 5PD	HFC no LFC and 1 point in the path history without GN header	77 bytes

The figures given in Table 9 are without any additional overhead from security, GeoNetworking or Access layer header. The security overhead is typically 100 bytes if the signing certificate is omitted, 230 bytes if the signing certificate is attached. This overhead represents typically the most significant overhead to be transmitted. Thus, the typical range for a VAM size is between 178 bytes (case 6 with security) and 367 bytes (case 1 with security and certificate).

The VAM generation time is mainly contingent upon the dynamic behaviour (e.g. speed, distance, orientation) of the individual VRU or cluster of VRUs (a group of VRUs identified by a single VAM). More details to the optional cluster operation of VRUs can be found in ETSI TS 103 300-3 [i.35]. The generation periodicity *T_GenVam* is bounded by the parameters given in Table 10. It has to be mentioned that the low frequency container of the VAM is not always present. It should be included at least every 2 000 ms in case it is used by the individual VRU. In ETSI TS 103 300-3 [i.35] the time between two consecutively transmitted VAMs ranges from 100 ms up to 5 000 ms. It can be assumed that for a typical pedestrian VRU (VRU profile 1) the generation time ranges from 1 000 to 5 000 ms. Overall communication requirements can be found in Table 11.

Table 10: Parameters for VAM generation as specified in ETSI TS 103 300-3 [i.35] (clause 8)

Parameter	Type	Meaning	Recommended value
T_GenVamMin	Time in ms	The minimum time elapsed between the start of consecutive VAM generation events. For LFC 200 ms should be used.	100 ms
T_GenVamMax	Time in ms	The maximum time elapsed between the start of consecutive VAM generation events.	5,000 ms
T_AssembleVAM	Time in ms	The time allocated for assembling a VAM packet in the facilities layer.	50 ms

Table 11: VAM generalized communication requirements as described in [i.115]

VRU use cases		PTW (vehicles)	Bikes		Pedestrians		
Requirements	Messages	All Messages	VAM	DENM	VAM	DENM's	Comment
Transmission Rate		PTW's behave like vehicles and with respect to the requirements targeted in this report no additions are expected here except higher position accuracy	1-5Hz	-	1-10Hz	-	VAM 10 Hz for Roadworkers on Highway
Transmission dynamics			low	high	low	high	
Area of relevance urban			70m	70m	70m	70m	
Area of relevance rural roads			>150m	>150m	>150m	>150m	
Area of relevance rural highways			>500m	>500m	>500m	>500m	
Message Size			350 Bytes	350 Bytes	350 Bytes	350 Bytes	
Message Latency, according to current			CAM	DENM	CAM	DENM	For MCM to be defined
Message validity							urrently not defined
Message priority			Not defined	Defined	Not defined	Not defined	
Transmission mode			Multicast	Multicast	Multicast	Multicast	
Transmission type			Repetitive	Event	Repetitive	Event	
Urban network message channel load			50%	>'3%	see C2C-CC position paper on "Road Safety and Road Efficiency Spectrum	>1%	As the density of Bikes can be accepted some factors more then vehicles but the rate is a lot less.
Rural roads network message channel load			>5%	>1%		>1%	% channel load is the allocated % of the channel load where 100% represents the maximum channel load before the channel congestion state is reached
Highway network message channel load			>1%	>1%		>1%	
V2V			-	-	-	-	
I2V and V2I			-	-	-	-	
V2E and E2V			X	X	X	X	
Reception Propability Requirement			Standard	Standard	Standard	Standard	
Security requirements			C-ITS	C-ITS	C-ITS	C-ITS	
Liability Impact			NO	NO	NO	NO	
Functional Safety Requirements			ASIL QM	ASIL QM	ASIL QM	ASIL QM	No automation expected
SOTIF			No	No	No	No	Refer to FSR
Position Accuracy level A			a<0.5m	a<0.5m	a<0.5m	a<0.5m	

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6.6 Manoeuvre Coordination (MC)

6.6.1 Introduction

Manoeuvre Coordination (MC): CCAD as part of CCAM [i.29] introduces Automation use cases such as lane change and overtake. More of such use cases related to automation have been recognized and will be realized in CCAD applications. Initial research such as the one executed in the AutoNet2030 [i.37] or TransAID [i.57] EU projects focusses on these aspects as well as projects further introduced in the coming years all leading to standardisations of at least the related message generating Manoeuvre Coordination Service (MCS) currently studied in the ETSI work programs DTS/ITS-00185 (ETSI TR 103 578 [i.125]) and DTS/ITS-00184 (ETSI TS 103 561 [i.127]), a service which is triggered by CCAD applications.

The Manoeuvre Coordination Service support connected automated driving by enabling vehicle C-ITS-Ss to exchange information about their intended Manoeuvres. This exchange enables that two or more vehicle C-ITS-Ss to coordinate with each other to efficiently and safely perform a Manoeuvre (e.g. a lane change or lane merge). It also improves the prediction of the future locations of nearby vehicle C-ITS-S. Roadside C-ITS-Ss can assist vehicle C-ITS-Ss by suggesting specific Manoeuvres, such as a speed change a lane change [i.18].

In contrast to the CA service, which can provide the past trajectory information (*pathHistory* data element), MCS enables C-ITS CCAD applications to exchange information about the intended future trajectories, and coordinate in case of conflict.

6.6.2 MC information dissemination

The Manoeuvre Coordination Message (MCM) is a broadcast message that is expected to include basic information about the transmitting C-ITS-S as well as additional information depending on the type of C-ITS-S. For vehicle C-ITS-Ss, the MCM is expected to include the intended (or planned) Manoeuvres and one or more desired (or alternative) trajectories. Each trajectory is a spatial-temporal description of the vehicle C-ITS-Ss trajectory in the next 5 to 10 s. While the planned trajectories are used by C-ITS applications to improve the prediction of future locations of nearby vehicle and to detect conflicts, the desired trajectories are used to request a coordination between vehicles. The message format has not been standardized yet, but MCMs that contain only a planned trajectory could have a size of around 300 bytes, and this size is increased up to around 600 bytes when a desired trajectory is added according to the TransAID EU project deliverable D5.1 "Definition of V2X message sets" [i.17]. The message generation rules are identified by CCAD applications but are not defined yet. It is expected that MCMs are generated continuously at a rate between 1 Hz and 10 Hz depending on the context as identified in the TransAID EU project deliverable 5.2, "V2X-Based Cooperative Sensing and Driving in Transition Areas" [i.18]. The idea behind the continuous message exchange is the early detection of the need of a Manoeuvre coordination. It is not yet clear whether the triggering is realized by specific CCAD applications or that MCS itself will include triggering conditions. The MCS could include triggering conditions while also having the possibility of being triggered by an application. For roadside CCAD applications, the MCMs are expected to include specific advices for specific vehicle C-ITS-Ss, to e.g. suggest a given speed or a lane change according to the TransAID EU project deliverable D5.1 "Definition of V2X message sets" [i.17]. Thus, the MCMs transmitted by roadside C-ITS-Ss are expected to be smaller in size (although they can include advices for multiple vehicles) and transmitted less frequently than those transmitted by vehicle C-ITS-S.

Besides the recognized planned and intended trajectories it can also be imagined there will be a need for proposed trajectories and may be mandatory trajectories. As for instance as presented in Figure 11 Lane Change Assist at Bus stop (LCA-B), Vehicle S wants to overtake the stationary Bus. Any Road user or other ITS-S equipped road safety stakeholder could analyse the road traffic situation based on received C-ITS information combined with other sensor data and advice or manage the road users how to act to realize an efficient and safe resolution of the situation.

Instructions on legal bases could be provided by IVI and DENM messages but also suggestions could be made how to behave. This could be done by providing proposed trajectory patterns to the road users in the relevance area.

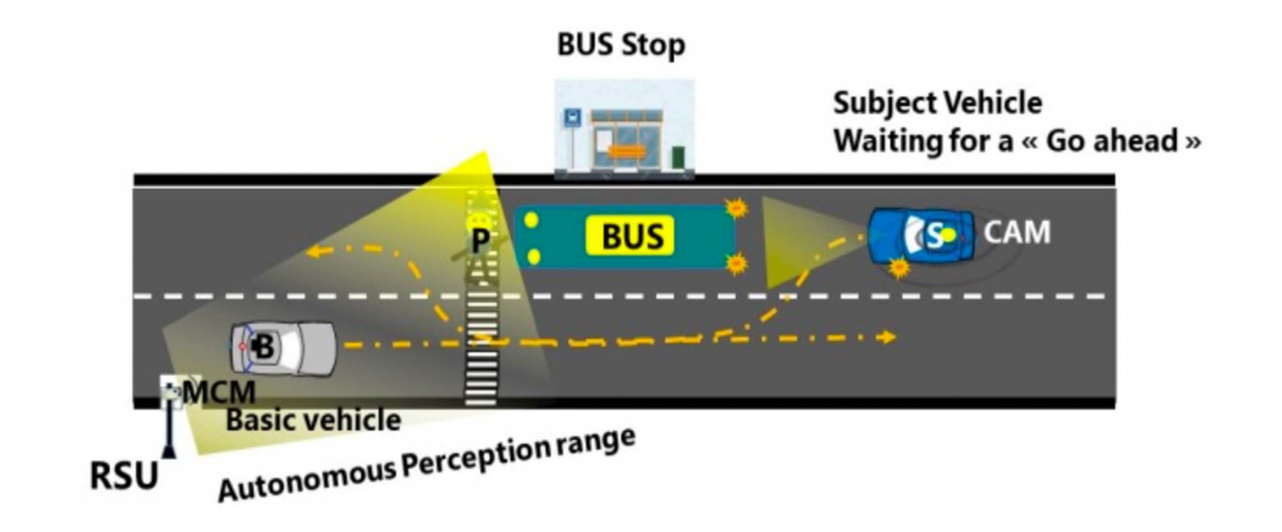

Figure 11: LCA-B Situation description

By using one of these methods the situation of shared liability is avoided. The legal binding methods based on IVI and warning based on DENM are not covered here but are covered as part of Release 1 user services operation.

Proposed trajectories are expected to be mostly used in specific use cases for instance at dangerous crossovers, schools and bus stops as in Figure 11. As the nature of use is similar to that of an intended trajectory it may be assumed that for the purpose of the present document the communication requirements are similar.

At the moment only planned, intended and proposed trajectories are recognized. For the purpose of for instance emergency and public transport, mandatory trajectories could be an additional trajectory message. The mandatory trajectory could be used by police, ambulance, fire brigade and public transportation. For the purpose of the MCO concept this is considered.

6.6.3 MC MCO communication requirements

It has been argued that MC is not specific safety related however the impact of actions related to MC information exchange has safety related effects and therefore MCM data exchange should be seen as safety related. As these are intended to be used for Automation related actions by the vehicle itself ASIL levels may apply. Something which may result in more stringent communication requirements. We can expect that higher guaranties of data delivery and more robust operation of the communications will be required. Projects have not yet resulted in usable parameters, therefore only some assumptions can be made. Table 12 provides some expected requirements.

Table 12: MCM communication requirements as described [i.115]

Manoeuvre Coordination Service	Planned Trajectory	Initiated Trajectory	Proposed Trajectory	Mandatory Trajectory	
Requirements / Message	MCM	MCM	MCM	MCM	Comment
Transmission Rate	1-10Hz	1-10Hz	1-10Hz	1-10Hz	
Transmission dynamics	Medium	Medium	Medium	Medium	Depends on vehicle's own speed
Area of relevance urban	>150m	>150m	>150m	>150m	
Area of relevance rural roads	>150m	>150m	>150m	>150m	
Area of relevance highways	>500m	>500m	>500m	>500m	
Message Size Urban/Rural/Hiughway	1000 - 1300 Byte. Message size changes depending on length of predicted vehicle's own trajectory and number of alternative trajectories. All trajectories included in one MCM				
Message Latency, According to Current					Currently not defined
Message validity					Currently not defined
Message priority					Currently not defined
Transmission mode	Multicast	Multicast	Multicast	Multicast	
Transmission type	Repetitive	event, repetitive	event, repetitive	event, repetitive	the most important MCM for planned and alternative trajectories must be sent repititive
Urban network message channel load	see C2C-CC position paper on "Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving"				
Rural roads network message channel load					
Highway network message channel load					
V2V	X	X	X	X	
I2V and V2I		X	X	X	
V2E and E2V					
Reception Propability Requirement	Same Release 1	Same Release 1	Same Release 1	Same Release 1	
Security requirements	C-ITS	C-ITS	C-ITS	C-ITS	
Liability Impact	NO	NO	NO	NO	
Functional Safety Requirements	ASIL QM or higher	ASIL QM or higher	ASIL QM or higher	ASIL QM or higher	Functional safety requirement is derived from application
SOTIF	NO	NO	NO	NO	Refer ro FSR
Position Accuracy level A	Depending on Use Case	Depending on Use Case	Depending on Use Case	Depending on Use Case	In most cases it moves to 0.5 m

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6.7 Basic CACC and platooning

6.7.1 Introduction

There are 2 parallel developments ongoing:

- ACC specifications covers automation levels 1 and 2 (SAE J3016 [i.128]) there where Cooperative ACC (CCAD) covers the levels 3 to 5. Current CACC communication requirements are captured in the ETSI TR 103 299 [i.32].
- Truck Platooning is of high interest to logistic companies and truck manufactures as it is expected lower employee costs, reduce gasoline consumption and decrease emission. Therefore, all European Truck manufacturers are cooperating in realizing platooning in the ENSEMBLE EU project [i.31] leading to an expected deployment by 2022-2025. Communication requirements are derived from the Ensemble deliverables and platooning study currently realized in the ETSI work program DTS/ITS-00156 (ETSI TR 103 298 [i.126]) and further developed in coming years.

Truck Platooning: Among the multiple platooning projects, an example is the EU project ENSEMBLE [i.31] working on a first version of Platooning. The Truck manufactures are expected to use multiple channels.

6.7.2 CACC information dissemination

Definition ETSI TR 103 299 [i.32]: "CACC is an in-vehicle driving assistance system that adjusts automatically the vehicle speed to keep a target time gap $\triangle t_{target}$ with a Target Vehicle (TV) while keeping a minimum safety distance with it" (see Figure 12).

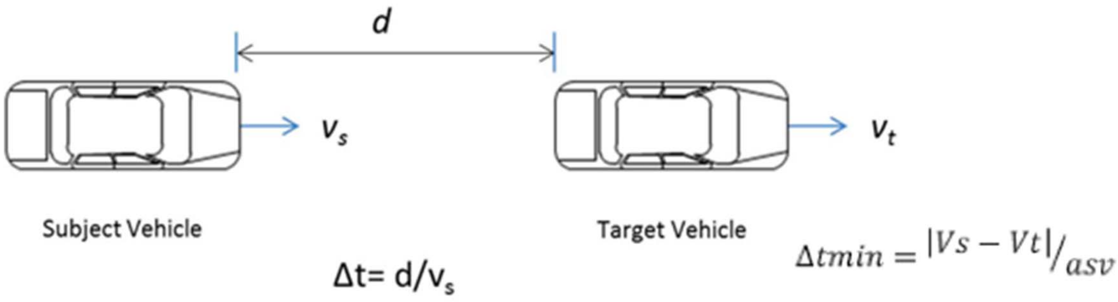

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Figure 12: CACC is an in-vehicle driving assistance, as defined in [i.115]

As identified by the use case descriptions in the ETSI TR 103 299 [i.32] report, only one-use case (UC007) requires some additional short-range data sharing besides SPAT/MAP messages received from the infrastructure. This information exchange requires only very limited bandwidth in a relatively small relevance area in a message broadcasting setup. The information may be included as part of the CAM (in a C-ITS backward compatible way) or be an additional message type with small message size. It is assumed not using significant more bandwidth.

In principle current CACC functional requirements as depicted in ETSI TR 103 299 [i.32], do not require more accurate requirements compared to what is covered by the C2C-CC BSP [i.45] except for the triggering conditions. CACC requires a higher CAM rate similar to the extended CAM rate presented as for the PAM in the platooning use case which shows a maximum CAM rate of 30Hz, leading to a drastically increases MCO requirement on the CAM transmission as noted by the ETSI TR 103 299 [i.32] clause 9.1.2.2. It will double the number of messages.

Increased lane level position accuracy will be required for advanced CACC and will require more stringent system positioning accuracy requirements leading to integrate additional position augmentation methods with the support of additional C-ITS information exchange, as identified in clause 6.3.3.

6.7.3 Platooning information dissemination

No clear definition is available but in the ENSEMBLE project [i.31] three platooning levels A, B and C are defined.

- Level A attributes:
  - Longitudinal coordinated automated control for the whole velocity ranges from 0 to maximum cruise velocity (depending on country regulations). The longitudinal control remains the driver's responsibility.
  - Maximum number of trucks of 7 is considered for platoon level A in ENSEMBLE.
  - A minimum time gap of 0,8 seconds @ maximum cruise velocity (depending on country regulations).
  - New members of a running platoon can only join from the rear.
  - Under adverse conditions like bad weather, slopes, etc., the drivers have the responsibility to increase the time gap or disengage the platoon completely.
  - The driver is responsible for the dynamic drive task in case of system failures. The system needs to be fail-safe.
  - Interaction with platooning user services and infrastructure is technically available.
- Level B, t.b.d.
- Level C, t.b.d.

The ENSEMBLE project recognized a number of communication layers including a Service, Strategic, Tactical, Operational and System Elements layer as defined in "V1 Functional specification for intelligent infrastructure" paper [i.31].

It clearly identifies different communication layers with different functional as well as non-functional (Functional Safety (ISO TS 26262 [i.90]), Safety of the Intended Functionality (SOTIF, ISO PAS 21448 [i.93]), privacy and security related) requirements. Communication with infrastructure on strategic as service level is recognized. For MCO these are not considered. Only the tactical and operational layer communication requirements are considered.

For platooning the CAM is extended with a Platooning Container to show the platooning capabilities and platooning status (this is also good for other vehicles so they can identify platoons when they meet any).

Platooning requires increased awareness from members of the platoon. Information which may also help other road users. This could be just small CAMs transmitted with different generation rules (based on early analyses but not specified in the current released deliverables from ENSEMBLE the rate could go up to twice the normal maximum CAM rate in addition to the already standard CAMs being transmitted). The definition of these CAMs could be realized by extending the current CAM specification or defining a separate Platooning Awareness Message (PAM). For readability of the document and keeping standard CAM information exchange separate from the extended Platooning awareness, in the following paragraphs the acronym PAM is used. It is not advised to combine this awareness information as part of the Platooning Control Message (PCM) because of the data nature and way of transmission. PAMs are sent in multicast and PCMs in unicast.

There are different ways the PAMs can be transmitted:

- The PAMs can be seen as an extension of the CAM and transmitted as such with a different generation rule and a different priority:
    - In case of no congestion on the channel all PAMs are sent.
    - In case of congestion on the channel:
        - The PAMs can be negated and not transmitted and CACC deactivated. This possibly as it is so crowded that it has no sense to have the CACC activated.
        - The PAMs can be automatically forwarded to a specific agreed channel or via the SA assigned one.
- All PAMs can be transmitted statically on a specific channel and when congestion in this channel occurs:
    - All others are not transmitted and CACC is degraded.
    - All others are forwarded statically to a different channel or via a SA assigned one. This forwarding could be depending on congestion levels in the appropriate channel(s).
- All PAMs are sent in channel selected by Service Announcement Essentional Message (SAEM). PAMs may also be sent in another specific channel assigned fixed or by mains of service announcement (SAEM, ETSI EN 302 890-1 [i.58]) assignments even for each platoon specified by the platoon leader. The assignment could for instance depend on the congestion ratios in the channels.

PAMs have similar dynamic and safety impact risks as standard CAMs and therefore it is assumed that for the transmission and use of these messages no additional Functional Safety or SOTIF requirements need to be realized.

PAMs may be sent in a smaller relevance area then standard CAMs, maybe dynamically depending on the size of the Platoon.

Based on the expected message transmissions, a 100 % single channel (of the 60 % CBR level as defined for Release 1 systems) occupation can be expected when there are only a few platoons in the same areas. This channel occupation is only in the area where active platoons are present. Initially this will be only on the highways but indications showing that a certain level of platooning may also be expected in urban areas in longer term. As highways also go through urban areas, it is not clear but currently not assumed that other information exchange could exists in the same channel as PAMs will be transmitted. Although level A platooning on highways only is considered today, for an MCO concept also level B and C expectations need to be considered.

Platoons are controlled by means of a platoon control state machines and required Platooning Control Message (PCM) exchange. A typical exchange flow is presented in Figure 13. PCMs can be exchanged in a specific channel but also use a channel selected by the platoon leader announced via a Service Announcement (SAEM, ETSI EN 302 890-1 [i.58]). PCMs are transmitted in a unicast or broadcast transmission mode (in ENSEMBLE [i.31] unicast is specified). For the operation of the platoon, the operation of the platoon state machine is essential and not properly working has safety relevant consequences. It is essential for this information exchange that the Safety of the Intended Functionality (SOTIF) and FSRs are met. Which may lead to additional communication requirements. This is addressed in clause 6.3.3.

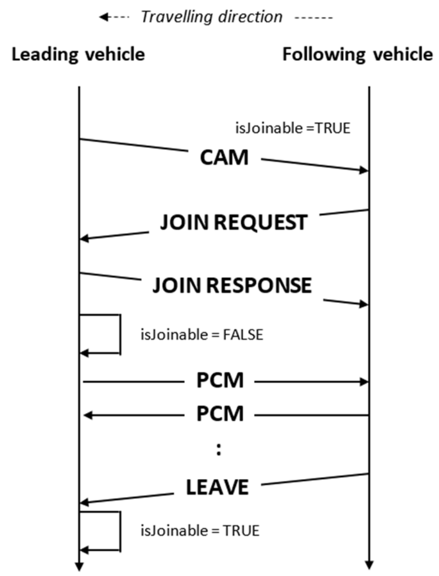

Figure 13: PCM information exchange (ENSEMBLE [i.31])

As Level B and C are not yet defined it is assumed that future developments require additional information exchange and therefore flexible extendibility of the channel usage should be encouraged. Mechanisms such as SAEM assignment where the user service can be found could be considered.

6.7.4 CACC and platooning MCO communication requirements

Although the content and negotiation methods used by CACC and Platooning may differ, the MCO requirements do overlap and therefore are here combined. As still many CACC and Platooning developments are expected in future, current MCO communication requirements are only initial requirements.

More accuracy related to the derived requirements are not required for the definition of an MCO concept except for Functional Safety and SOTIF as these are system configuration dependent. It can be recognized that although the PAMs provide a more refined dynamic status knowledge of the other vehicles in the platoon or CACC string, they are providing similar to CAM for Platooning level A (Release 2) also only ASIL QM level is considered. For higher platooning levels this may be extended. PAMs should be just seen as addition but smaller (less information) CAMs. They can also be used by normal traffic (not participating in the platoon) to improve the quality of the information. PCMs are Platooning specific and will be exchanged with an additional trust level (additional security). For higher ASIL levels additional measures are expected, such as transmitting the PCMs on multiple channels possibly with additional requirements such as in spectrum at a relative far distance and by means of different technologies. Further analyses are needed. Table 13 provides the initial requirements not considering possible ASIL level requirements.

Table 13: CAM, PAM, SAEM and PCM related communication requirements as defined in [i.115]

Platooning Use cases		Awareness		Control		Comment
Requirements	Messages	CAM	PAM	SAEM (option)	PCM	PAM could be simple CAM
Transmission Rate		1-10 Hz	10-20 Hz	1Hz	1-50 Hz	PCM's are very dynamic and depending on level
Transmission dynamics		low-high	static	low	low-high	CAM's + PAM's = Total awareness required.
Area of relevance		Standard	70-100m	200m	70-100m	Platooning members 2-3
Area of relevance		Standard	200m	200m	200m	Platooning members 2-7
Message Size		200-800 Bytes	200 Bytes	300 Bytes	400 Bytes	
Message Latency, According to Current		CAM	CAM	SAM		
Message validity						Currently not defined
Message priority		Only for Day-1	Not defined	Not defined	Not defined	
Transmission mode		Multicast	Multicast	Multicast	Unicast	PCM's could also be Broadcast
Transmission type		repetitive	Sequencial	Event	repetitive	
Urban network message channel load		see C2C-CC position paper on "Road Safety and Road Efficiency			see C2C-CC position paper on "Road Safety and Road Efficiency	
Rural roads network message channel load						
Highway network message channel load						
V2V		X	X	X	X	
I2V and V2I		-	-	-	-	
V2E and E2V		-	-	-	-	
Reception Propability Requirement		Standard	Standard	Standard	High	
Security requirements		C-ITS	C-ITS	C-ITS	High	PCM's to include encription
Liability Impact		NO	NO	NO	High	
Functional Safety Requirements		ASIL QM	ASIL QM or higher	ASIL QM	ASIL QM or higher	Functional safety requirement is derived from application
SOTIF		NO	NO	NO		Refer to FSR
Position Accuracy level A		a<1m	a<1m	X	X	Only level A is identified

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6.8 Intersection safety

6.8.1 Introduction

Intersection safety covers all those use cases increasing safety in especially urban environment and managed by regional or local authorities. Coordination of what use cases are of importance are brought to European level by participation of main European cities represented in C-ROADS [i.47] to specify the most relevant urban use cases and their applications. As traffic controllers manage the traffic via the intersection traffic lights this is called Intersection Safety (IS). Agriculture (AEF [i.39]) is interested in Agriculture Safety (AS) and Urban Rail is interested in Urban Rail Safety (URS). Only Train crossings as use cases and their application is part of Intersection Safety (the others are included here as they have some requirements of interest but have only a limited impact on MCO).

6.8.2 IS information dissemination

Release 1 applications include the support for basic traffic light use cases making use of Signal Phase And Timing (SPAT) and related Map (MAP) message services as specified in ISO TS 19091 [i.10] and related protocols in ETSI TS 103 301 [i.40]. Extension of these applications for Release 2 show the support for more complex road crossing use cases and support for emergency and public transport prioritization via Signal Request Extended Message (SREM) and Signal request Status Extended Message (SSEM) exchange. Unequal crossings such as rail-road crossings use case descriptions and weather forecast (short term, slippery road) and road conditions (sensors in/at the road and sensors in vehicles) application requirements are currently being drafted by authorities themselves or in cooperation with C-ROADs [i.47].

Early single channel message assessment showed that in case of full penetration the channel can get congested by only CAM and DENM dissemination. For the time being it was agreed to allow SPATEM/MAPEM/IVIM in the same channel at the lowest priority. To ensure proper operation today and in the future of Infrastructure oriented applications and awareness services it needs to be considered that existing SPATEM/MAPEM/IVIM message transmissions are supported with offloading mechanisms and that Release 2 applications such as SREM and SSEM will preferably use other channels. As the MCO requirements are application depending on each of these applications need to be separately assessed:

- Extended SPAT triggering applications and MAP awareness service detailing will lead to more complex messages and a higher rate of updates. As it can be expected an increasing population of C-ITS-S in an urban area, a conservative handling of the congestion levels will lead to the negation of the transmission or off-loading of lowest priority messages such as generated by the SPAT and MAP services. It is therefore advised to agree assigning a channel to which the off-loading can take place to accommodate the continuation of the SPATEM and MAPEM transmission realizing robust and C-ITS Interoperability compliant operation of Intersection safety application. This off-loading could be facilitated by triggering the SA services.

- Unequal crossings such as a rail-road crossing, are from a signaling point of view not much different from standard SPATEN/MAPEM message transmissions realized for Release 1 SPAT/MAP standard road crossing use cases and have no additional requirements other than what is addressed in the previous bullet. Additionally, it could transmit DENM warning messages not expected to lead significant additional requirements.

- Traffic prioritization applications are typical Release 2 applications. We need to distinguish automated and not automated when equipped:

  - When not automated, depending on their role and state the prioritized vehicular C-ITS-S sends CAMs and possibly DENMs to warn traffic when the vehicle is in the emergency state (the CAM should be sufficient as the CAM includes the emergency state). As especially in Urban Areas at full penetration of C-ITSs, the SCH0 can become congested and as other messages then CAM and DENM have the lowest priority they will be the first not to be transmitted based on the reached congestion level.

  - When Automated vehicles could make use of the MCS to indicate the intended lines to drive. In case there is a high penetration of automated vehicles the priority could be part of the negotiation and by that the MCM could be used in a mandatory way (see clause 6.6). The detailed communication with the road infrastructure and operation of MCS needs further studies but indicates intensive additional communication between C-ITS-Ss can be expected.

  To ensure that priority is only given to the allowed authority vehicles a separate trusted information exchange is required as specified as SREM and SSEM in the ISO TS 19091 [i.10] supported by communication protocols specified in the ETSI TS 103 301 [i.40]. It is advised that for the prioritization related information exchange a separate channel used to ensure predictable application behaviour in future. Channel selection needs to be identified in pace with Release 2 to ensure interoperable use.

With respect to Release 2 MCO we should consider the information exchange covered by SPATEM, MAPEM will be extended and SREM and SSEM will be introduced followed probably by MCM as part of Release 3. It therefore needs to be considered to include offloading mechanisms for the basic SPATEM/MAPEM/IVIM and realize other Infrastructure information exchange specific for Infrastructure applications in a separate channel.

6.8.3 AS information dissemination

For Agriculture Safety, it is necessary to make a distinction between the case when Agriculture equipment is on the normal road and when it is on private territory. C-ITS solutions are being realized by organizations such as the AEF [i.39] in Europe:

- In case the Agriculture equipment is actively participating in normal road environment and when equipped with a C-ITS-S it should be interoperable with other vehicles and send CAMs based on its active state as other vehicles. Additionally, it could send warnings, for instance about its size or special behaviour. This is something normally supported by the DENM but an extension of DENM might be required. As no special additional information exchange is required it can be seen as a special vehicle and does not have additional MCO requirements as Release 1 user services.

- In case the Agriculture equipment is on private territory no C-ITS requirements are applicable except when agriculture related information is exchanged in the safety relevant 5,9 GHz band. In that case those transmissions are not allowed to interfere the normal operation of C-ITS-Ss or have impact on the performance of C-ITS applications operating in this band. As agriculture applications are non-safety oriented, related information exchange should take place in the non-safety related bands or in other available spectra. Still C-ITS protocols can be used.
  One of the applications to use C-ITS protocols is the possible use of C-ITS standardized PAI related services. It is currently expected that there are no significant or conflicting MCO requirements recognized.

6.8.4 Urban Rail Safety (URS) information dissemination

Urban Rail ITS makes use of CBTC systems to exchange safety related information among Urban Rail trains and their infrastructure. It does not have protocols as specified for C-ITS and coexistence needs to be established at the media (spectrum) level. To support coexistence, C-ITS protocols are available including the Interference Management Zone Message (IMZM) message services including its triggering conditions as defined in ETSI TS 103 724 [i.84] supporting the mechanism to ensure the protection of CBTC systems.

According to EU spectrum regulation Urban Rail ITS has priority in channel SCH6 and road ITS in the other channels. According to this regulation only I2V (roadside) C-ITS-S equipment can transmit in this channel which limits the possible use of this channel for C-ITS until coexistence is defined. Roadside C-ITS-Ss have mostly a fixed location and therefore the possible interference can be easily managed. These criteria can also be achieved for C-ITS application, C-ITS testing, as testing needs to be done in a controlled environment in which possible interference can be excluded.

Independently of the actual deployed technology the most efficient way of deploying Urban Rail ITS would be the smooth integration into the overall ITS concept including MCO. A sharing of the same resources would lead to a flexible deployment scenario of the two ITS systems. In ETSI TR 103 580 [i.113] three different deployment scenarios have been identified and the resource usage has been analysed for these scenarios:

- Single Zone Controller (ZC)
- Three Zone Controllers
- Three Zone controllers including a Platform Screen Doors (PSDs).

In most cases the single ZC scenario will be valid, whereas the other two scenarios are only valid in rail station environments and track crossing scenarios.

In ETSI TR 103 580 [i.113] the channel loads for the three scenarios have been analysed for 5 MHz channels. In Table 14, Table 15 and Table 16 these values have been scaled to 10 MHz channels to be comparable with the other applications presented in the present document.

Table 14: Communication resources for Urban Rail ITS, single ZC case [i.113]

CBTC Application services	Period in ms	Average packet length in Bytes	Maximum packet length in Bytes	Packets/s	Throughput in Bits/s average	Throughput in Bits/s max
Location Report to one ZC	200	200	800	5	8 000	32 000
Periodic Train Functional Status message	300	500	1 000	3,3333	13 333	26 667
On demand specific status message	300	500	1 000	3,3333	13 333	26 667
Movement of authority from ZC	600	200	1 000	1,6666	2 667	13 333
Information about Line from ZC	400	500	1 400	2,50	10 000	28 000
Burst Traffic for Track data base update (File transfer)	100	50	150	10	4 000	12 000
Request for Health train status	500	50	100	2	800	1 600
Total **Channel load 10 MHz channel estimated):**					**52 133** **2,0 %**	**140 267** **3,0 %**

Table 15: Communication resources for Urban Rail ITS, three ZC case [i.113]

CBTC Application services	Period in ms	Average packet length in Bytes	Maximum packet length in Bytes	Packets/s	Throughput in Bits/s average	Throughput in Bits/s max
Location Report to one ZC	200	200	800	5	8 000	32 000
Location Report to a second ZC	200	200	800	5	8 000	32 000
location Report to a third ZC	200	200	800	5	8 000	32 000
Periodic Train Functional Status message	300	500	1 000	3,3333	13 333	26 667
On demand specific status message	300	500	1 000	3,3333	13 333	26 667
Movement of authority from ZC	600	200	1 000	1,6666	2 667	13 333
Information about Line from ZC 1	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 2	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 3	400	500	1 400	2,50	10 000	28 000
Burst Traffic for Track data base update (File transfer)	100	50	150	10	4 000	12 000
Request for Health train status	500	50	100	2	800	1 600
Total					**88 133**	**260 267**
Channel load 10 MHz channel (estimated):					**3,26 %**	**7,16 %**

Table 16: Communication resources for Urban Rail ITS, three ZC case including PSD [i.113]

CBTC Application services	Period in ms	Average packet length in Bytes	Maximum packet length in Bytes	Packets/s	Throughput in Bits/s average	Throughput in Bits/s max
Location Report to one ZC	200	200	800	5	8 000	32 000
Location Report to a second ZC	200	200	800	5	8 000	32 000
location Report to a third ZC	200	200	800	5	8 000	32 000
Periodic Train Functional Status message	300	500	1000	3,3333	13 333	26 667
On demand specific status message	300	500	1 000	3,3333	13 333	26 667
Platform Screen Door monitoring and control approaching, in station and leaving station	100	50	150	10	4 000	12 000
Movement of authority from ZC	600	200	1 000	1,6666	2 667	13 333
Information about Line from ZC 1	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 2	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 3	400	500	1 400	2,50	10 000	28 000
Platform Screen Door	100	50	200	10	4 000	16 000
Burst Traffic for Track data base update (File transfer)	100	50	150	10	4 000	12 000
Request for Heath train status	500	50	100	2	800	1 600
Total					**96 133**	**288 267**
Channel load 10 MHz channel (estimated):					**3,70 %**	**7,30 %**

It has to be taken into account that a typical Urban Rail ITS will deploy two redundant channels in order to increase the reliability of the communication. Taking these evaluation results the worst-case resource usage would be in the range of 14,6 %. An average value will be around 6 % for a redundant dual channel implementation.

6.8.5 Intersection safety MCO communication requirements

Infrastructure Safety applications are expected to require extended use of channel capacity compared to Release 1 usage. As SCH0 is considered to be fully used by Release 1 RSU related applications and awareness services could consider the specific SCH6 which is currently allocated for I2V information exchange specific.

Agriculture equipment equipped with a C-ITS-S only operate in the safety related channels for general road safety applications. As agriculture specific applications are not road safety related these agriculture specific applications need to make use of the non-safety related channels for their agriculture specific application for specific information exchange. Non-safety related applications can use road C-ITS related services in the non-safety related bands.

Urban Rail could require the transmission of the Interference Management Zone Message (IMZM)) in SCH6 by means of a C-ITS-S by Urban Rail stakeholders. Only C-ITS-S RSU's and C-ITS-Ss in controlled environments could transmit in SCH6 according to the European spectrum regulation identified in clause 5.2.3.

Table 17 provides the expected extended data exchange require for Release 2 and beyond IS applications.

Table 17: Intersection related communication requirements as defined in [i.115]

VRU use cases	Infrastructure Safety				Prioritized Traffic					Environmental Polution			Legal	
Requirements / **Messages**	**SPATEM**	**MAPEM**	**DENM's**	**IVIM**	**CAM**	**DENM's**	**MCM**	**SPAT**	**MAP**	**CAM**	**DENM's**	**IVIM**	**IVIM**	**Comment**
Transmission Rate	1-10Hz	1-10Hz	-	-	1-10Hz	-	1-10Hz	1-10Hz	1-10Hz	1-10Hz	-	-	-	
Transmission dynamics	low	high	high	high	high	high	Medium	low	high	low	high	high	high	
Area of relevance urban	150m	150m	150m	150m	150m	150m	150m	150m	150m	70m	>70m	>70m	>70m	
Area of relevance suburban roads	150m	150m	150m	150m	150m	150m	150m	150m	150m	>150m	>70m	>70m	>70m	
Area of relevance highways	500m	500m	500m	500m	500m	500m	500m	500m	500m	>200m	>70m	>70m	>70m	
Message Size	1200 Byte		1000 Bytes	400 Bytes	average 400 Byte (250-800 Bytes)	1000 Bytes	1000 Byte	1200 Byte		average 400 Byte (250-800 Bytes)	1000 Bytes	400 Bytes	400 Bytes	for spectrum needs a combined message size for SPATEM, MAPEM, IVIM of 1200 Byte
Message Latency, According to Current	SPATEM	MAPEM	DENM	IVIM	CAM	DENM	MCM	SPATEM	MAPEM	CAM	DENM	IVIM	IVIM	
Message Validity														Currently not defined
Message Priority	Only for Day-1	Only for Day-1	Only for Day-1	Only for Day-1	Only for Day-1	Only for Day-1	Not defined	Only for Day-1	Only for Day-1	Only for Day-1	Only for Day-1	Only for Day-1	Only for Day-1	
Transmission mode	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	Multicast	
Transmission type	Repetitive	Repetitive	Event	Repetitive	Repetitive	Event	event, repetiive	Repetitive	Repetitive	Repetitive	Event	Event	Event	
Urban network message channel load	see C2C-CC position paper on "Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving"				<1%	<1%	<2%	<3%	<0%	<80%	<2%	<2%	<2%	For the awareness type of messages The amount of messages effected is identified but the amount of messages is not increasing only the size of the message is. See Footnote*
Rural roads network message channel load					<1%	<1%	<2%	<5%	<0%	<80%	<2%	<2%	<2%	
Highway network message channel load					<1%	<1%	<2%	<5%	<0%	<80%	<2%	<2%	<2%	
V2V	-	-	-	-	X	X	X	-	-	X	-	-	-	
I2V and V2I	X	X	X	X	X	X	X	X	X	X	X	X	X	
V2E and E2V	-	-	-	-	-	-		-	-	-	-	-	-	
Reception Propability Requirement	Standard	Standard	Standard	Standard	Standard	Standard	Same Release 1	Standard	Standard	Standard	Standard	Standard	Standard	
Security requirements	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	C-ITS	
Liability Impact	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Functional Safety Requirements														Not known at this time but in gernal only ASIL QM expected
SOTIF	No	No	No	No	No	No	No	No	No	No	No	No	No	Refer to FSR
Position Accuracy level A	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	

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6.9 High-definition sensor sharing

6.9.1 Introduction

See through of passing applications require High-Definition Sensor raw data exchange such as for video-frame exchange. Information exchange requiring high bandwidths. Advanced automation applications creating challenging requirements for current C-ITS systems.

6.9.2 High-definition sensor sharing information dissemination

High-Definition Sensor Sharing applications and other type of date require bulk (large to very large size packages) or streaming (continues bandwidth access) type of data transfers leading to high demanding spectrum constrains for each C-ITS-S supporting such applications., according to several studies and papers such as from the 5GAA spectrum requirements study [i.44] and in the Hybrid Communication CODECS workshop [i.102] recognizes the need for up to 500 MHz bandwidth for this.

6.9.3 High-definition sensor sharing MCO communication requirements

When considering the ITS European Spectrum regulation in the 5,9 GHz band (ECC Decision (08)01 [i.72]), it can be recognized that within this 5,9 GHz band the required bandwidth for such applications is not available. There is however a 2,16 GHz band in the 64 GHz spectrum allocated for ITS safety related user services according to ECC Decision (09)01 [i.94]. As no details are known at the moment these applications are not considered for MCO.

6.10 Non-safety ITS applications

6.10.1 Introduction

Applications such as software updates, Vehicle Health Monitoring, Security Credentials and System validation (new applications and new systems needs to be tested in life situations while not interfering operating C-ITS-Ss), are considered as non-safety related. All such applications need to make use of the non-safety related channels as defined in the ECC Recommendation (08)01 [i.73].

6.10.2 Non-safety ITS applications information dissemination

When it concerns any private C-ITS application, it is up to the specific private entity to manage how and by which manner the information is exchanged. To inform possible users, whether those are human or automated applications could be announced. For this an agreed interoperable way needs to be agreed.

6.10.3 Non-safety ITS applications MCO communication requirements

Only in case desired by private or common entities a common non-safety related SAEM exchange can be agreed, for which an interoperable specification will be needed. Operation of such SAS, as identified in clause 6.3.2, should be realized in a non-safety channel.

6.11 Testing and validation user services

6.11.1 Introduction

At the moment more than one channel is in use and with the expectation that all will be used it needs to be considered how to realize validation and to do compliance and system testing of C-ITS applications, services, C-ITS-Ss and technologies. Such activities need to be facilitated while other C-ITS applications are active.

6.11.2 Testing and validation information dissemination

Activities as described in clause 6.11.1 have to be realized in controlled environments such that these activities cannot be disturbed and in environments where they cannot interfere with the operation of other C-ITS applications and awareness services. Testing and validation in most cases are realized in restricted areas, for instance a test site.

6.11.3 Testing and validation user service MCO communication requirements

As from Urban Rail and from RSUs the locations are specific and can be well known, while from other moving around C-ITS stations this is not possible, the realization of testing and validation can be best realized in those channels in which fixed station-based systems such as Urban Rail and I2V C-ITS are transmitting and non-fixed are not active.

6.12 General MCO communication considerations

The amount of C-ITS Release 1 message services enabling applications or self-triggering awareness services to support the Release 1 use cases is limited. First only CA and DEN later extended with SPAT, MAP and IVI are all supported on a single channel. Release 2 application developments show the need for a large number of different behaving awareness services and message generating services. As identified in clause 5.5.3 the service behaviour is defined by the use cases and their scenarios realized by the applications and awareness services in which the varying use cases can result in very dynamic message generation. Data exchange requirements may differ extremely over time. To allow applications (including the awareness services) to operate robustly the following aspects need to be considered (including generalized findings from previous clauses):

- Some user services supported use cases could require the application to transmit messages on different channels depending on the type of C-ITS-S. It could be so that for instance a prioritized vehicle e.g. ambulance, emergency application transmits its messages in a more vehicle-oriented channel while the infrastructure related application transmits its messages in a different but I2V oriented channel.
- It is important that applications have a good knowledge whether they can trigger the transmission of messages and have knowledge of the communication possibilities statically extendable to dynamically, to realize robust operation of these applications.
- As applications have no knowledge of the existence of other applications, they do not know whether a channel in which it expects to transmit its messages is available or whether it is used by any other application. A mechanism is needed which could have an overview and inform applications of the possibilities to transmit.
- Continuity of the user service: Only the applications know the urgency of messages to be transmitted. In case there is sufficient bandwidth available prioritization of the message would not really be needed but there are a few cases when this is required:
    - The time urgency of the message to be transmitted could be improved when the ordering of the transmitting messages could be managed by knowledge about the time window in which messages should have been transmitted. Prioritization of some messages compared to other ones would also allow to improve the situation.
    - Service message usually have various types of content - some content being crucial for receivers. Only application can know whether crucial content is present in a specific message instant. Sharing such information by services to MCO along with service messages can help MCO ensuring proper handling of messages during congestion and offloading to proper channels.
    - Bandwidth limitation due to channel congestion leads to messages not being transmitted. Mechanisms to ensure that this doesn't happen are to be considered, such as informing applications of the communication possibilities or bringing message transmission flexibility offering lower layers to use other radio resources when available such as off-loading based on message prioritization.

  In both cases one or other form of message or application prioritization should be considered. Such prioritization could be generic based on generic rules or be based on a fixed list, supported by the C-ITS stakeholders.

- From the spectrum regulation it can be seen that in one ITS channel (CH6) only I2V transmissions are allowed. It is therefore clear that road infrastructure specific application related messages are transmitted in this channel. Therefore, could be considered to realize all extended SPATEM, MAPEM, IVIM and pre-emption I2V transmissions are realized in this channel. Messages of these types by other C-ITS-Ss should be sent on a different channel (for instance CH5).
- From the explanation of the operation of SAS (see clause 6.3.2), it is suggested to allow safety related SAEMs to be sent on any safety channel for applications targeting specific user groups. It is suggested to assign a dedicated channel for general use. Similar to this, the same approach can be used for non-safety related application triggered message transmissions in non-safety related channels.
  For general use a specific channel and specific communication parameters can be chosen to inform C-ITSs of the presence of general services. The settings but at least the channel may differ for safety and non-safety related services.
- 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.
- For Release 2 Functional safety related requirements beyond ASIL QM level are currently not considered. ASIL QM level does not introduce additional communications requirements on top of those required for Release 1. To support in-vehicle sub-systems to operate at a higher ASIL level, Release 2 improvements are expected to focus on improvement of the sensor data quality including the confidence level of the shared data. To determine the impact on MCO of higher ASIL levels further studies are needed.

7 Technical capabilities and limitations

7.1 Introduction

The following clauses present the identified technical capabilities and limitations that can influence the performance and operation of an MCO concept, and therefore should be taken into account. They include the spectrum needs, the transceiver configuration, multi-channel interference effects and some particularities of the access layer technologies.

7.2 Transceiver configurations

The capabilities of an MCO solution are limited by the transceiver configurations of the C-ITS-Ss. A C-ITS-S can be equipped with one or more transceivers operating in the 5,9 GHz C-ITS band. Each transceiver may operate in one channel, or more channels simultaneously. All transceivers of a C-ITS-S may implement the same wireless communication technology or different ones (e.g. ITS-G5, IEEE 802.11bd [i.104], LTE-V2X or 5G NR V2X). All C-ITS-Ss in the same network may not be equipped with the same number of transceivers. ETSI TR 103 576-2 [i.103] presents different implementation options for achieving C-ITS Interoperability and C-ITS backward compatibility with multiple communication interfaces.

The present document considers MCO technology agnostic concepts for the realization of single technology solutions. As coexistence methods supporting different technologies are not yet defined, mixed technology possibilities cannot be considered. In the following Table 18 different C-ITS-S configurations are listed.

Table 18: Transceiver setup

Configuration Index	Number of channels that an ITS-S is capable of accessing simultaneously	Technology Configuration
1	One	A
2	Two	A for both channels
3	Two	A for a channel, and A_x for the other channel
4	Multiple	A for all channels
5	Multiple	Any mixed combination of A and A_x

In the Table 18, "A" represents a radio technology (e.g. either ITS-G5 or LTE-V2X), and "A_x" represents a new iteration of the same radio technology (e.g. either IEEE 802.11bd [i.104] for ITS-G5 or 5G NR-V2X for LTE-V2X). In the present document, each C-ITS-S is assumed to support one of the configurations in Table 18.

NOTE: The MCO approach in conjunction with the transceiver configurations described in this clause will be taken into account in a following MCO standard based on the observations of the present document.

7.3 Channels with wider bandwidth

Multi-channel operation results in an increased system capacity by using multiple channels also simultaneously, enabling more applications and awareness services. Using multiple channels effectively leads to an overall increased use of spectrum bandwidth. Although current spectrum regulation in the 5,9 GHz ITS band is limited to the use of 7 × 10 MHz channels (see clause 5.2.3), technical solutions as identified in the IEEE 802.11-2020 [i.108], currently under development extension IEEE 802.11bd [i.104] of this standard, 3GPP LTE-V2X sidelink [i.117] and 3GPP 5G-V2X sidelink [i.119] specifications, support the use of wider channels. The use of wider channels have advantages and disadvantages which could be further analysed before being deployed (see e.g. [i.120], [i.121], [i.122],[i.123]).

Some typical technical benefits of wider channels may include:

- Resources could be pooled within wider channels, rather than being distributed into multiple independent channels, enabling more flexibility and a higher spectral efficiency.
- It may be simpler to operate in a single channel rather than using two or more separate channels, because the latter may involve a higher implementation complexity and/or communication overhead.
- A wider channel needs only one RF hardware chain, while multiple narrower channels might need more RF hardware chains.
- Wider channels may need less congestion control due to an increased statistical multiplexing gain, resulting in less limitation of communications range and message transmission rates.
- Unsynchronized adjacent channel interference effects, which can cause some impact for MCO, can be avoided within a wider channel bandwidth by using synchronous frequency multiplexing or shorter packet transmission times.

Some typical technical drawbacks of wider channels may include:

- A wider channel bandwidth might require better transmit/receive filters to ensure the same emissions and rejection capabilities of channels with smaller bandwidth, which may also include advanced signal processing algorithms.
- The use of non-adjacent radio channels is only possible via an MCO mechanism or a channel aggregation mechanism.
- With a fixed number of channel access priorities in a channel, wider channels have less flexibility in assigning these priorities.
- Unsynchronized cochannel coexistence of wide and narrow bandwidth communication may result in performance degradations. Hence, overlapping radio channels should be avoided.
- Compared to one wide channel, using different radio channels for different applications, data might be isolated among the channels, so that only relevant data needs to be decoded in the receiver. For example, truck platooning messages are not relevant to passenger cars.
- For safety-relevant services, additional protocol overhead could be expected to coordinate this channel sharing; otherwise, system delays may get out of control and cannot be kept within the limits required by these safety-relevant applications.

The proposed MCO concept should allow a future extension to wider channels and support various channel bandwidths without impacting services/applications. Detailed analyses of the advantages and disadvantages, including the combination of wider channel bandwidth with MCO, are outside the scope of the current document but are suggested to be further investigated by ETSI.

7.4 Channel load measurement

Both ITS-G5 and LTE-V2X make use of congestion control protocols based on the periodic measurement of the Channel Busy Ratio (CBR) metric. The CBR is a channel load metric used to control and distribute the channel access among C-ITS-S. CBR is an estimate of how much a channel is used based on listening on surrounding radio transmitters. It is defined in ETSI EN 302 571 [i.19] for ITS-G5 and in ETSI TS 103 574 [i.20] for LTE-V2X. For ITS-G5, the CBR is calculated according to clause 4.2.10 in [i.19], as the ratio of time when the received signal strength is higher than -85 dB over a period of 100 ms. For ITS-G5, the DCC_ACC component provides the local CBR value to the DCC algorithm as specified in the ETSI TS 102 687 [i.86]. For LTE-V2X, the CBR is calculated according to clause 5.2 in ETSI TS 103 574 [i.20], as the fraction of sub-channels whose S-RSSI exceeds a threshold -94 dBm for PSSCH, or the fraction of resources (2 PRB pair) whose S-RSSI exceed a threshold of -94 dBm for PSCCH with non-adjacent control and data resources. It is also measured over 100 ms.

Updated CBR information is needed to be able to satisfy the congestion control limits in both ITS-G5 and LTE-V2X and may also be needed to decide the channel(s) to be used. However, a C-ITS-S may only have updated CBR information about the channel(s) it is using. C-ITS-S could obtain this information via periodic exchange of the CBR with nearby C-ITS-S that may be listening to a different channel, hence may have corresponding CBR to its disposal. Alternatively, or additionally, C-ITS-S may also obtain this information with a nearby RSU that may have acquired CBR from other C-ITS-S operating in the adjacency. Channel load measurement in SAS currently is from ego-ITS-S but not from others. However, it may be up to the ITS-S implementation on the feasibility of the acquisition of CBR. That information could be needed by the C-ITS-S to transmit a packet.

In addition, an MCO concept could potentially require knowing the CBR of the different channels in order to decide the channel used to transmit each packet. That would also require updated CBR information of all the channels.

7.5 Multi-channel interference effects

7.5.1 Overview

In a multi-channel operation of a wireless system, different intra-system interference effects have to be considered. These effects might lead to a significant performance degradation of the system. In order to understand the possible mitigation techniques these effects will be presented in clause 7.4. Both transmitter and receiver parameters have an impact on the performance in an MCO environment.

In Figure 14 the basics of the interfering effects in an MCO operation are depicted with the focus onto the direct adjacent channel. Similar effects can be observed for the second adjacent channel, spurious emissions and any kind of blocking signal further away from the wanted channel.

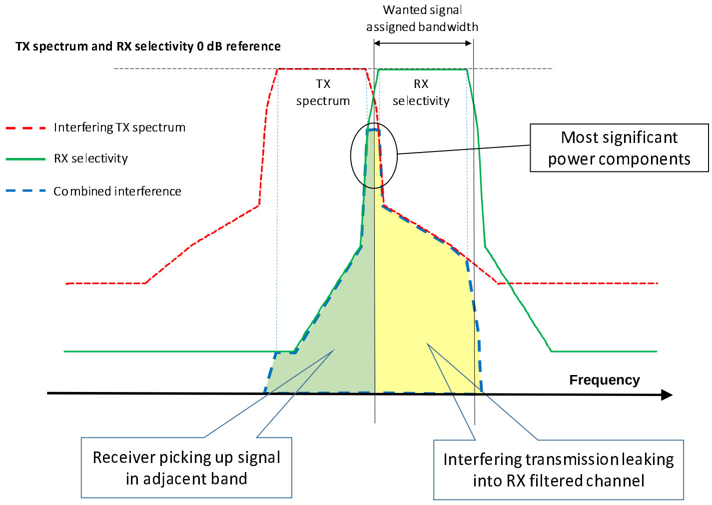


Figure 14: Impact of an interfering transmitter and a victim receiver on the reception of wanted signals, see ECC Report 310 [i.106]

NOTE: Here the out-of-band emissions in the wanted signal bandwidth is the main factor.

7.5.2 Unwanted emissions

7.5.2.1 Overview

Unwanted emissions are all kinds of emission of an interfering system which are not in the wanted emission band of this system. The unwanted emissions can be split into two main parts:

- Adjacent and second adjacent channel leakage or emissions; and
- Spurious emissions.

Unwanted emissions lead to interfering energy in the wanted band of the victim system. Unwanted emissions cannot be filtered by the victim system since the interfering energy is in the wanted band of the victim system. Unwanted emissions can be reduced by e.g. signal design and transmitter filtering at the interfering transmitter.

7.5.2.2 Adjacent and second adjacent channel leakage

The effects of the adjacent and second adjacent channel leakage of a transmitter is described by the transmitter mask as defined in ETSI EN 302 571 [i.19]. From the victim receiver side this effect cannot be mitigated by any kind of filtering. The leaked energy of the interfering transmitter is part of the wanted signal to be received and leads to an increased noise level.

7.5.2.3 Spurious emissions

The spurious domain frequency band starts at 250 % of the carrier bandwidth above and below the centre frequency of the emission of the interfering systems. For a 10 MHz system this is the 3rd adjacent channel starting at 20 MHz separation form the band edge of the reference channel. The levels of spurious emissions are regulated in ERC REC 74-01 [i.107]. For the MCO considerations the levels of spurious emission (-30 dBm/MHz EIRP) and the probability of occurrence are very low as compared to the adjacent channel effects. The real value of the interfering power in the spurious domain is significantly lower. Thus, they will not be considered further in the present document.

7.5.3 Blocking and selectivity

Blocking refers to the reduction of the receiver sensitivity, thus the degradation of its performance, in the presence of an off-channel interfering signal; the frequency offset of the interfering signal should generally cover a relatively large range of frequencies around the wanted signal. The reduction of the sensitivity of the receiver is called "desensitization" [i.106].

For the 1st adjacent channel and the 2nd adjacent channel the capability of a receiver to copy with these kinds of interference are specified as adjacent channel rejection ACR or adjacent channel selectivity ACS.

The robustness of the receiver against interfering signals further away than the 1st or 2nd adjacent channel are typically specified as blocking rejection.

7.5.4 Combined unwanted emission and selectivity effects

For the evaluation and simulation of the interfering effects in an MCO operation a combination of the two main effects (ACLR and ACS) into a single parameter will simplify the investigations. By combining and adding up the two interfering effects an interfering transmitter in an adjacent channel can be modelled as a simple interfering source transmitting a specific interference power. All relevant filtering effects (TX and RX) can be included into a single figure $P_{\text{TX\_int\_eff}}$, which is the transmitted effective interference power seen in a reference channel at the position of the interfering transmitter. $P_{\text{TX\_int\_eff}}$ is dependent on the specified values for the TX power mask, the ACR or ACS, the transmit power of the interfering transmitter and the chosen adjacent channel. For the co-channel case, $P_{\text{TX\_int\_eff}}$ would be the actual TX power of the interfering transmitter:

$$P_{\text{TX\_int\_eff}} = P_{\text{i\_ACL}} + P_{\text{i\_ACS}}$$

More general $P_{\text{TX\_int\_eff}}$ and the single components of the interference power are functions of offset frequency Δf from the band edge of the wanted signal:

$$P_{\text{TX\_int\_eff}}(\Delta f)\ [\text{mW}] = P_{\text{i\_ACL}}(\Delta f)\ [\text{mW}] + P_{\text{i\_ACS}}(\Delta f)\ [\text{mW}]$$

where Δf is the frequency offset from the band edge. In order to calculate the effective interference power in a received bandwidth the $P_{TX\_int\_eff}(\Delta f)$ [mW] has to be integrated over this bandwidth.

Based on $P_{TX\_int\_eff}$ the interfering power at the antenna of the victim receiver $P_{RX\_int\_eff}$ can be calculated by taking into account the actual PathLoss (*PL)* between the interfering transmitter and the victim receiver:

$$P_{RX\_int\_eff}[mW] = P_{TX\_int\_eff}[mW] / PL \text{ or}$$

$$P_{RX\_int\_eff}[dBm] = P_{TX\_int\_eff}[dBm] - PL[dB]$$

As described above this can also be expressed more general taking into account the frequency dependency of the interference effects:

$$P_{RX\_int\_eff}(\Delta f)\ [mW] = P_{TX\_int\_eff}(\Delta f)\ [mW] / PL \text{ or}$$

$$P_{RX\_int\_eff}(\Delta f)\ [dBm] = P_{TX\_int\_eff}(\Delta f)\ [dBm] - PL\ [dB]$$

where Δf is the frequency offset from the band edge.

7.5.5 Other effect

7.5.5.1 Overloading

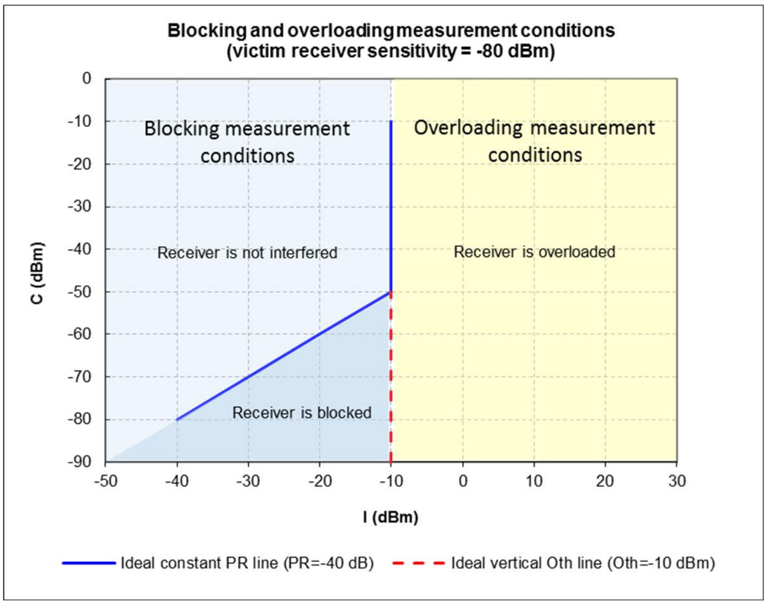


Figure 15: Receiver blocking and overloading measurement ranges [i.106]

Blocking and overloading of a receiver are two different phenomena and should not be confused. Figure 15 shows the C(*I*) curve of an ideal receiver with a Protection Ratio (PR) of -40 dB and an overloading threshold (Oth) of -10 dBm.

Overloading occurs when the receiver front-end is fully overloaded by a strong off channel interfering signal. This results in the degradation of the PR of the receiver due to the "gain compression" and "noise increase" caused respectively by the third order and second-order nonlinearity of the receiver LNA. The receiver selectivity also affects the overloading threshold level. In such case the interfering signal level expressed in dBm is called the "Overloading threshold" of the receiver.

When the receiver front-end is fully overloaded the receiver may become "blind" and thus unable to receive anything at all in contrast to the blocking and unwanted emission effects where only the communication range will be reduced. Additionally, beyond the overloading threshold the receiver is interfered by the interfering signal independent of the wanted signal level, as explained in Figure 15.

7.5.5.2 Intermodulation

The Intermodulation phenomenon arises from non-linearity of the amplifier in the receiving chain. The theoretical output signal of the amplifier can be described by a polynomial formula in the form:

$$y(t) = ax + bx^2 + cx^3 \qquad (1)$$

where ax is the wanted output and bx^2, cx^3, etc. are unwanted intermodulation products due to the mixing of two or more interfering signals. Intermodulation is the only parameter requiring two or more interfering signals.

When considering only two signals of frequencies f_1 and f_2, the amplifier will generate:

$$cx^3 = c(A_1\cos(\omega_1 t) + A_2\cos(\omega_2 t))^3 = c\frac{3}{4}A_1^2A_2\cos(2\omega_1 t - \omega_2 t) + c\frac{3}{4}A_2^2A_1\cos(2\omega_2 t - \omega_1 t) + \dots \qquad (2)$$

This means that two signals of frequencies $2f_1 - f_2$ and $2f_2 - f_1$ appear in the receiver: these are the third order intermodulation products. 2nd order products (and higher order even number products) do not appear within the receiver's bandwidth and can be ignored. Higher order odd number products can also have an impact, but not as significant as 3rd order products.

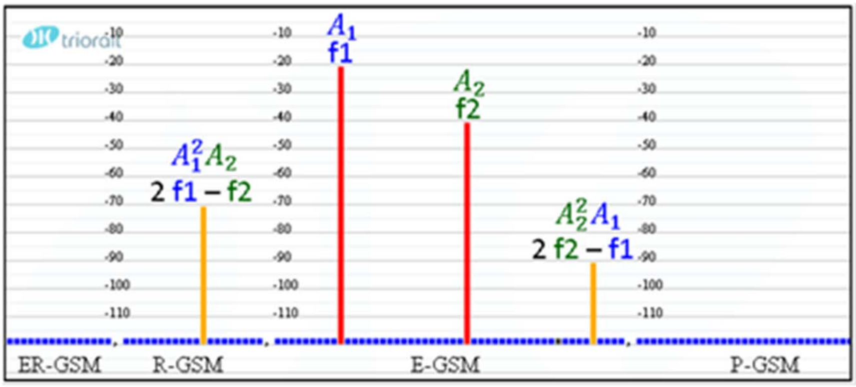


Figure 16: Generation of intermodulation products [i.106]

A receiver operating at frequency f_0 is interfered by third order intermodulation products when the following conditions are met:

$$f_0 \approx |2f_1 - f_2| \quad (3)$$

and the strength of the signals A_1 and A_2 is above a given threshold. Note that some standards/specifications define one of the interfering signals (typically the signal close to the receiver) with a system specific modulation whereas the second one remains unmodulated. See Figure 16.

7.5.5.3 CSMA/CA energy detection threshold

In the case of CSMA/CA based systems, such as ITS-G5, if the potential interfering system in the adjacent channel operates with a very small distance from the victim receiver antenna, it can happen that the generated interference by the interfering system reaches the level of the energy detection threshold. From the victim point of view this would lead to a positive sensing result and the transmission operation will be delayed. Here the adjacent channel interference will have a direct influence onto the transmission operation of the victim system. Furthermore, it could lead to an increased estimated channel load and thus a triggering of the DCC mechanism.

As an example, based on ITS-G5 in LOS transmission conditions between the interfering TX with TX power of P_{TX_I} = 23 dBm in the adjacent channel and the victim systems antenna with 8 dBi antenna gain, this effect can happen in a distance up to around 15 m having in mind the energy detection threshold of -65 dBm in a 10 MHz channel.

Under very dense traffic conditions this effect might have to be taken into account especially when operating in DCC conditions.

7.5.6 Summary MCO interference effects

In the scope of the definition of MCO the main effects to be taken into account are the adjacent channel leakage of the transmitter and the adjacent channel selectivity of the receiver. In addition, in CSMA/CA based systems, the energy detection process in the receiver has to be considered.

Other effects (e.g. overloading and intermodulation) of adjacent channel interference from any kind of device operation in the adjacent channels can influence the performance of the system. These effects are mainly related to very close proximity operation of the devices and thus need to be taken into account in the development process of the integrated device or of the multi-channel chips. These effects are very much related to the detailed architecture of the devices.

For further investigations in the scope of the present document the focus will be put onto the ACL, ACS and energy detection threshold effects.

The impact of these effects, which are quantified in Annex A (ITS-G5) and Annex B (LTE-V2X), is investigated through simulations in clause 8.

8 Simulations and Verifications

8.1 Introduction

This clause includes the evaluation of the impact of MCO usage in respect to interference on adjacent channels. System level simulation results are presented with respect to the key performance indicators (KPIs) presented in clause 8.2, based on the scenarios detailed in clause 8.3 and under the settings specified in clause 8.4.

The conclusions obtained in clauses A.6 and B.6 show that the multi-channel interference effects for LTE-V2X and ITS-G5 are very similar. Based on this observation, the evaluations for the impact of MCO usage in respect to interference on adjacent channels effects on the MCO performance are expected also similar for both ITS-G5 and LTE-V2X, and only ITS-G5 is simulated in clause 8 for convenience.

Results are provided without any reference to a specific service and should not be seen as performance assessment of services that have been already well investigated in other documents. Nonetheless, some settings such as message size and generation interval are freely inspired by CAMs, which are the most known messages at the time of writing.

8.2 Key performance indicators

8.2.1 Introduction

In this clause, the KPIs used for the evaluation of the impact of the interference between adjacent channels are specified. In particular, details are provided on how Packet Reception Ratio (PRR), range, Inter-Packet Gap (IPG) and Channel Busy Ratio (CBR) are calculated.

8.2.2 Packet Reception Ratio

The PRR is obtained considering the transmitter-receiver distance within intervals of d_{STEP} m. The k-th interval is within $(k\text{-}1){*}d_{STEP}$ and $k{*}d_{STEP}$.

For one transmission packet with index n, $Y_{n,k}$ is the number of receiving vehicles that are located within the k-th distance interval from the transmitter, and $X_{n,k}$ is the number of vehicles with successful reception among those $Y_{n,k}$ vehicles.

The average PRR for the k-th distance interval is calculated as $(X_{1,k}+X_{2,k}+X_{3,k}+....+X_{N,k})/(Y_{1,k}+Y_{2,k}+Y_{3,k}+....+Y_{N,k})$ where N denotes the number of transmitted messages.

The distance interval is set to $d_{STEP} = 100$ m.

8.2.3 Range (maximum distance with PRR = 0,9)

The Range is here defined as the maximum distance to have PRR above 90 %, with PRR as defined in clause 8.2.2.

It is to note that Range is strictly related to PRR as it provides a synthetic number from the curve relating PRR and distance.

8.2.4 Inter-Packet Gap

The IPG (sometimes referred as update delay, see Figure 17) is the average time difference between two consecutive successful receptions of packets sent from the same transmitter to the same receiver that is located within a given distance from the transmitter. The IPG implicitly allows to evaluate the correlation between consecutive errors.

We evaluate the IPG in the form of Complementary Cumulative Distribution Function (CCDF) for all transmitter-receiver pairs within a communication range threshold of 200 m.

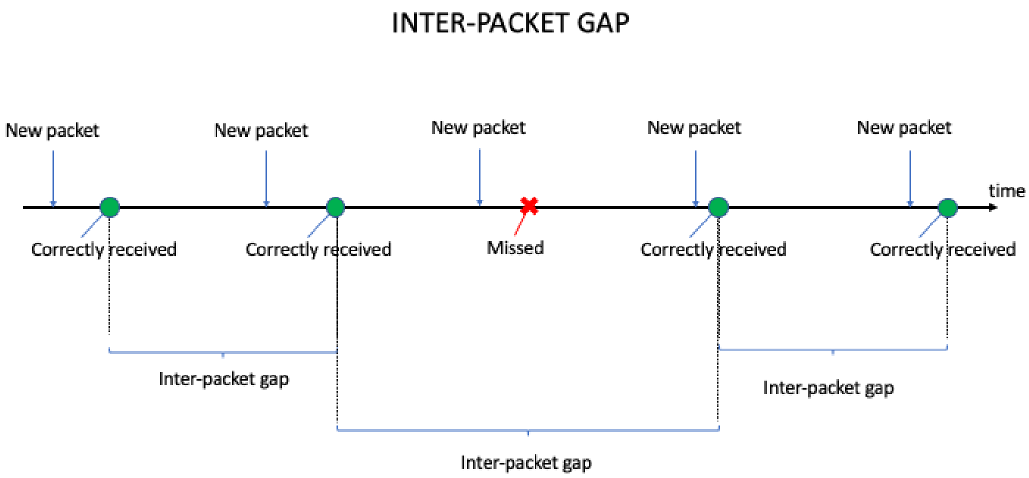


Figure 17: Example of IPG

8.2.5 Channel Busy Ratio

This metric is used to estimate the load in a single radio channel, obtained as the average of CBR values as detailed hereafter.

In ITS-G5, each vehicle calculates the CBR as a time-dependent value between zero and one, representing the fraction of time that a single radio channel is busy with transmissions. The CBR assessment should be according to clause 4.2.10 in ETSI EN 302 571 [i.19], that uses the following equation:

$$CBR = \frac{T_{busy}}{T_{CBR-ITSG5}}$$

where T_{busy} is the period of time in milliseconds when the strength of received signals over a period of $T_{CBR\text{-}ITSG5}$ exceeds -85 dBm [i.21] and $T_{CBR\text{-}ITSG5}$ is equal to 100 ms [i.21].

8.3 Road layout and vehicle distribution

A straight road with 6 lanes, corresponding to 3 lanes in each direction of 4 m width, is considered (see Figure 18). The length of the highway is 8 km.

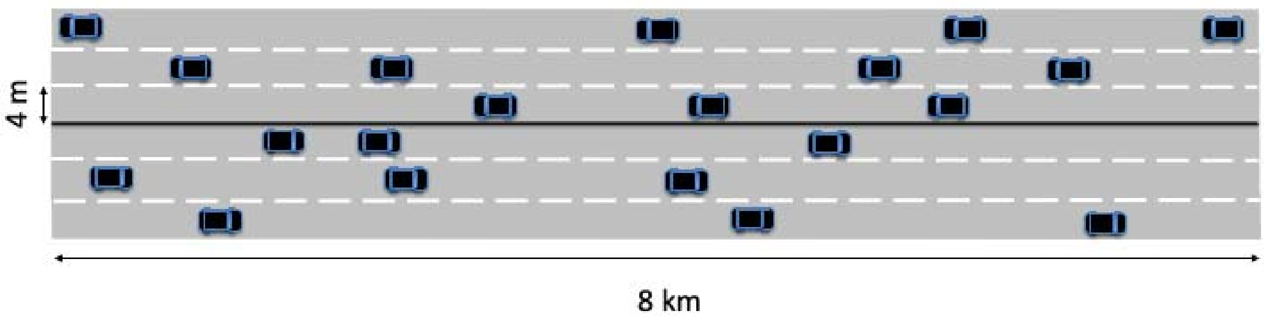


Figure 18: Road layout

The initial position of the vehicles is evenly distributed over the lanes and uniformly distributed over the road length (approximating a Poisson distribution). Each vehicle moves at a constant speed, randomly selected using a Gaussian distribution with the average indicated value and a standard deviation equal to one tenth of the average speed. Vehicles exiting in one direction will enter again the scenario in the same lane, at the opposite side (wrap around approach).

Results in urban scenarios are also shown in clause E.5.

8.4 Simulation settings

8.4.1 Introduction

In this clause, the main settings and most relevant models are introduced.

8.4.2 Traffic generation

Each vehicle is assumed to generate new messages of a fixed size every a given interval. Specifically, the adopted message size is 350 bytes. The generation interval is set 100 ms, meaning a packet generation at 10 Hz, unless DCC (clause 8.4.3.3) triggers a larger generation interval.

Given the objective to evaluate the effect of MCO interference, the derived conclusions are expected to have broader validity. To confirm this, a different size for the packet is considered in clause E.4.

NOTE: The scope is here not to evaluate a given service but to investigate the impact of multi-channel interference. For this reason, a given size and a given periodicity are used causing variable vehicular density to produce variable channel load.

8.4.3 Access layers settings

8.4.3.1 Introduction

This clause details the settings adopted at the physical layer and the DCC protocol.

8.4.3.2 Physical layer settings

ITS-G5 nodes are assumed to transmit at either 23 dBm or 33 dBm EIRP, with 3 dBi antenna gain at the receiver, and 6 dB receiver noise figure.

The access category Best Effort (BE) is adopted, corresponding to AIFS equal to 110 us, CW equal to 15. The sensing threshold, when a preamble is detected, is set to -85 dBm, whereas it is set to -65 dBm otherwise. The CBR is updated based on those signals that exceed -85 dBm.

The modulation and coding scheme corresponding to QPSK modulation and ½ coding rate is assumed.

8.4.3.3 Decentralized congestion control

DCC is applied as in ETSI EN 302 663 [i.22]. Specifically, based on the CBR, the minimum generation interval is calculated as:

$$T_{gen-DCC} = \min(\,1,\ t_{pack}[ms] \cdot 4 \cdot \tfrac{CBR-0.62}{CBR}) \text{ [seconds]}$$

where *CBR* is the measured CBR and t_{pack} is the duration of the message.

8.4.4 Physical layer modelling

8.4.4.1 Introduction

This clause details how the physical layer is modelled in the adopted simulator. In particular, clause 8.4.4.2 focuses on the path loss model, clause 8.4.4.3 describes how the interference from adjacent channels is taken into account, and clause 8.4.4.4 specifies how errors are identified.

8.4.4.2 Propagation

Given that a highway scenario is investigated, a rural channel model is considered. The adopted channel model is a modified version of the one detailed in the ECC Report 68 [i.105] for the rural scenarios, hereafter simply denoted as ECC68 rural. Specifically, the pathloss is calculated as follows:

$$PL_{dB}(d) = \begin{cases} 20\log_{10}\left(\frac{\lambda}{4\mu d}\right) & if\ d \le d_{T0} \\ 20\log_{10}\left(\frac{\lambda}{4\mu d_{T0}}\right) - 10n_0\log_{10}\left(\frac{d}{d_{T0}}\right) & if\ d_{T0} < d \le d_{T1} \\ 20\log_{10}\left(\frac{\lambda}{4\mu d_{T0}}\right) - 10n_0\log_{10}\left(\frac{d_{T1}}{d_{T0}}\right) - 10n_1\log_{10}\left(\frac{d}{d_{T1}}\right) & otherwise \end{cases}$$

where d is the transmitter-receiver distance, λ is the wavelength of the signal, $d_{T0} = 128$ m is the first breakpoint distance, $n_0 = 2{,}8$ is the path loss factor beyond the first breakpoint distance, $d_{T1} = 512$ m is the second breakpoint distance, $n_1 = 3{,}3$ is the path loss factor beyond the second breakpoint distance.

The modification, compared to the original ECC Report 68 [i.105], is in a smaller value for the breakpoint distance. The rational is that the original models in ECC Report 68 [i.105] have been developed for the link between a device, with height 1,5 m, and an access point, with height 10 m to 25 m (the addressed technologies were BWA systems, such as WiMax®).

NOTE: The adopted model has been selected as it appears in good agreement with the general experiences in highway scenarios with a low vehicle density. In particular, it has been preferred to WINNER+, B1, which is often used for similar evaluations, as the latter has been designed for urban scenarios. For a low vehicle density, the WINNER+, B1 model appears to significantly overestimate the path-loss in highway conditions. For scenarios with a high vehicle density on a highway the ECC 68 rural model might underestimate the path-loss. Since a vehicular channel model needs to consider both the environment as well as the vehicle density but such channel models does not exist, the ECC 68 rural model is chosen as a compromise. Results adopting the WINNER+, B1 model are shown in clause E.3.

The path loss as a function of the transmitter-receiver is shown in Figure 19 in comparison with the WINNER+, B1 model, which has been designed for urban dense scenarios and is often used for V2X, and the free-space path-loss model.

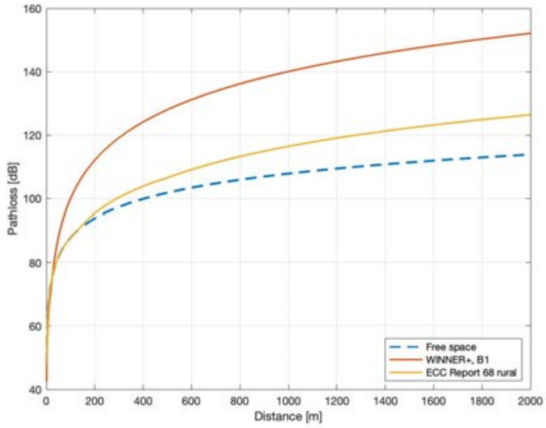


Figure 19: Path loss vs. distance with ECC Report 68 [i.105] rural model and references

Correlated log-normally distributed large-scale fading (shadowing) is considered, with 25 m decorrelation distance.

Small-scale fading is implicitly included in the performance curves detailed in clause 8.4.4.4.

Results adopting the WINNER+, scenario B1, model are provided in clause E.3.

8.4.4.3 MCO interference modelling

The interference from one channel to an adjacent channel is modelled following the calculations of clause A.6.

In particular, given a transmission from a generic node j in one channel, the interference perceived at a generic node i in a different channel, at a distance d_{ji} is calculated as $P_{ji}^{MCO} = P_{ji}^{r} + L_{ji}^{adj}$. Here, P_{ji}^{r} denotes the received power in dBm that depends only on the path loss between node i and node j. The adjacent channel selectivity and interference effects are incorporated by L_{ji}^{adj}, which describes the gain from the channel of node i to node j in dB and is always negative.

As motivated by Annex A.6, when an EIRP of 33 dBm is adopted, L_{ji}^{adj} equal to -32,1dB and -46,4 dB is assumed in the first and second adjacent channel, respectively. When an EIRP of 23 dBm is adopted, L_{ji}^{adj} equal to -25,9dB and -40,6 dB is assumed in the first and second adjacent channel, respectively.

8.4.4.4 Error evaluation

Interference is modelled as additive, Gaussian and white, proportional to its duration and occupied bandwidth.

Thus, given one transmission, the average interference is calculated over the duration of the signal and the obtained value is added to the noise power. The average Signal To Noise And Interference Ratio (SINR) is then derived.

Given the average SINR, the correctness of a transmission is statistically derived from Packet Error Rate (PER) vs. SINR curves obtained adopting link level simulations.

In particular, the curve reported in Figure 20 is used, where PER is 0,1 at SINR = 3,1 dB. This curve was obtained through link-level simulations, with the following assumptions: 1 transmitting antenna and 2 receiving antennas with 1 × 2 IRC (Hermitian noise covariance Matrix) equalizer, highway LOS fading model as per ETSI TR 103 257-1 [i.24] channel estimate based on preamble and feedback loop, perfect control channel decoding, perfect synchronization.

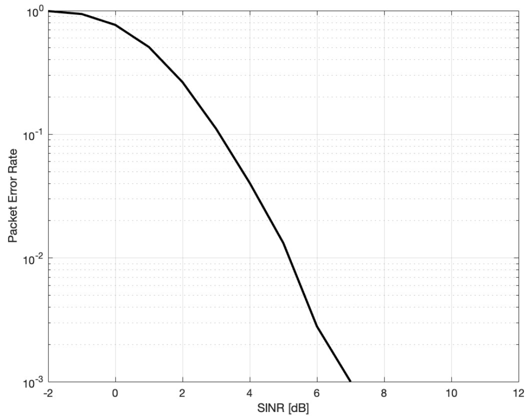


Figure 20: Adopted curve of packet error rate vs. signal to noise ratio (MCS 2, 350 bytes)

In Figure 21, the received power varying the transmitter- receiver distance is shown considering only the path loss, given an EIRP of either 23 dBm or 33 dBm and the path loss model detailed in clause 8.4.4.1. The power level corresponding to the CBR threshold (i.e. -85 dBm) and that corresponding to a SINR of 3,1 dB are also shown as references.

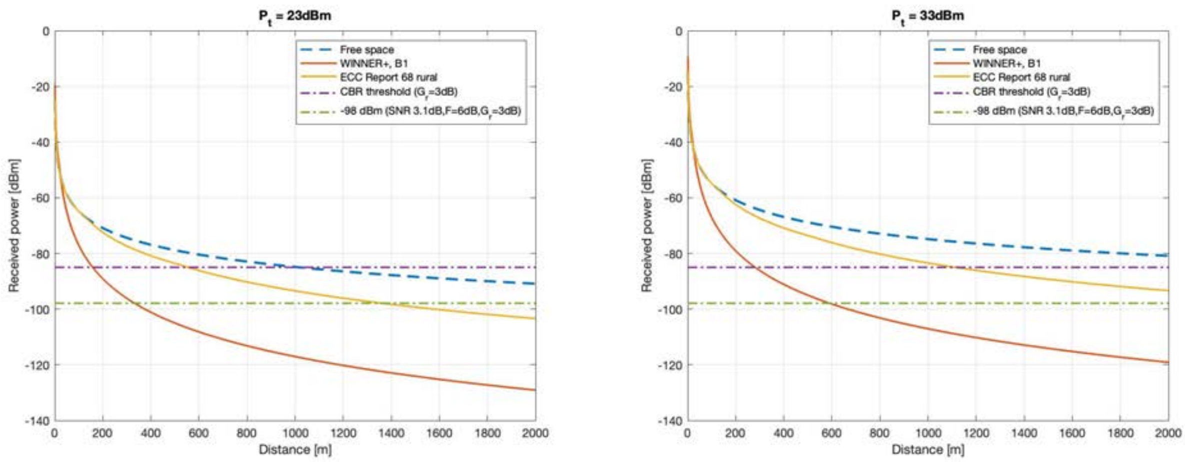


Figure 21: Received power vs. the transmitted receiver distance assuming path loss only

8.5 Simulation results

8.5.1 Introduction

Results are provided in two situations. The first one, explored in clause 8.5.2, assumes balanced traffic in two channels, the reference channel and either traffic in the adjacent channel or with an empty channel in between, i.e. the second adjacent channel. Objective of clause 8.5.2 is to provide indications about the impact of MCO interference under realistic traffic distributions and investigate how much it is convenient to distribute the load over the various channels. The second one, addressed in clause 8.5.3, considers one reference channel interfered by the first adjacent channel with variable load. The scope in this case is to understand how much the load in the first adjacent channel affects the performance in the reference channel.

8.5.2 Balanced data traffic in adjacent channels

8.5.2.1 Introduction

Given the settings detailed in clauses 8.3 and 8.4, here simulation results are provided assuming five scenarios, as detailed in clause 8.5.2.2. Data traffic is here assumed evenly (on average) distributed over two channels or transmitted using a single channel.

8.5.2.2 Scenarios for the investigation in balanced traffic

The following five vehicle densities with different average vehicle speed are considered.

- Scenario 1: 12,5 vehicles/km at 130 km/h.
- Scenario 2: 25 vehicles/km at 120 km/h.
- Scenario 3: 50 vehicles/km at 110 km/h.
- Scenario 4: 75 vehicles/km at 100 km/h.
- Scenario 5: 100 vehicles/km at 80 km/h.

The rational for the selected speed derives from the Van Aerde model [i.111] considering a maximum capacity of 2 200 vehicles per hour (achieved at 50 km/h), a maximum speed of 140 km/h, and a maximum density of 200 vehicles per km (traffic jam). The output of the referred model and the selected speed for each of the given densities is shown in Figure 22.

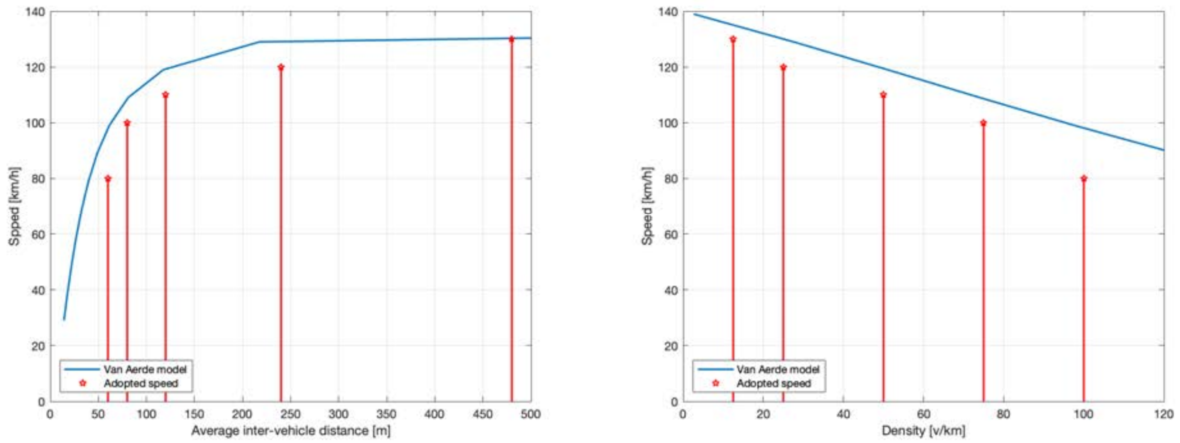


Figure 22: Derivation of speed as a function of density in the adopted scenarios

Per each of the five densities, the following cases are compared:

- Half of the vehicles use the reference channel, and the others simply do not transmit.
- Half of the vehicles use the reference channel, and the others use the 1st adjacent channel.
- Half of the vehicles use the reference channel, and the others use the 2nd adjacent channel.
- All of the vehicles use the reference channel.

8.5.2.3 Preliminary considerations

In Table 19, preliminary considerations on the simulated scenarios are provided. Per each vehicle density and both EIRP values (23 dBm and 33 dBm), the following metrics are shown.

- The "in CBR-range" counts, for a generic vehicle, the average number of neighbouring vehicles in the same channel which are sensed above the CBR threshold of -85 dBm during transmissions.

- The "estimated CBR with no collision" is derived by multiplying the average number of vehicles in CBR-range by the average number of packets per second and the duration of a packet transmission; given that it does not consider collisions, it is an upper bound to the average CBR if no traffic is present in adjacent channels.
- The "median CBR (simulated)", which provides the minimum and maximum values of the median CBR obtained in the various cases; specifically, the minimum corresponds to the case with no traffic in the adjacent channels and the maximum to the other half of vehicles in the first adjacent channel.

The numbers reported in Table 19 show that scenarios 1 and 2 with 23 dBm and scenario 1 with 33 dBm are lightly loaded, with a median CBR that never goes above 0,15, and the data traffic becomes high in scenario 5 with EIRP = 23 dBm and scenarios 3-5 with EIRP = 33 dBm. DCC, which adopts a threshold limit of 0,62 for the CBR, is triggered only in scenario 5 with EIRP = 33 dBm.

Comparing the estimated CBR with the minimum value of the median CBR it is also possible to have an idea of the collisions occurring in each scenario. As an example, in scenario 5 with EIRP = 23 dBm and no interference from adjacent channels, the CBR is 0,343, which is much lower than the estimated 0,57, meaning that there are a relevant number of concurrent transmissions.

Finally, comparing the minimum and maximum values of the median CBR it can be noted that the impact of transmissions in the first adjacent channels is not negligible in terms of CBR, with an increase that mostly ranges between 5 % and 10 %.

Table 19: Preliminary considerations about the scenarios with balanced traffic

	EIRP 23 dBm In CBR-range (same channel)	Estimated. CBR single channel, no collisions	Median CBR (sim)	EIRP 33 dBm In CBR-range (same channel)	Estimated. CBR single channel, no collisions	Median CBR (sim)
Scenario 1 (half of 12,5 v/km)	6,9 vehicles	0,07	0,046-0,051	13,9 vehicles	0,14	0,087-0,092
Scenario 2 (half of 25 v/km)	13,8 vehicles	0,14	0,087-0,097	27,8 vehicles	0,29	0,169-0,182
Scenario 3 (half of 50 v/km)	27,7 vehicles	0,28	0,177-0,192	55,7 vehicles	0,57	0,333-0,357
Scenario 4 (half of 75 v/km)	41,4 vehicles	0,43	0,264-0,286	83,5 vehicles	0,85	0,486-0,508
Scenario 5 (half of 100 v/km)	55,4 vehicles	0,57	0,343-0,374	111,4 vehicles	> 1	0,585-0,604* (*DCC active)

8.5.2.4 PRR versus distance

From Figure 23 to Figure 27, the PRR versus distance is shown in the five scenarios. In each figure, two plots are shown, referring to EIRP = 23 dBm and 33 dBm, respectively. In each plot, four curves are compared:

- Only half of the vehicles in one channel (the others are not equipped or not transmitting).
- Half of the vehicles in one channel and the other half in the 1st adjacent channel.
- Half of the vehicles in one channel and the other half in the 2nd adjacent channel.
- All of the vehicles in one channel.

In Figure 23, the PRR versus distance is shown with reference to scenario 1. In this case the channel is lightly loaded. As observable, with an EIRP of 23 dBm the presence of adjacent channel interference is almost irrelevant. With an EIRP of 33 dBm, all results are similar, although it can be noted a small degradation when all the vehicles are transmitting in one channel (dashed curve).

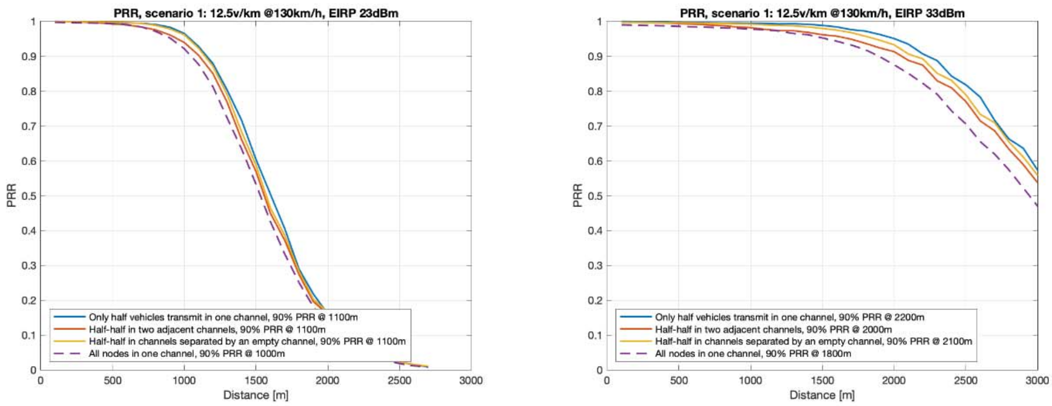


Figure 23: PRR vs. distance in scenario 1 with balanced traffic

In Figure 24, the PRR versus distance is shown with reference to scenario 2. Results are still very similar when the EIRP is 23 dBm, which corresponds to a CBR always below 0,1 in the reference channel when the traffic is split into two channels (solid curves) and 0,175 when it is all in one channel (dashed curve). A small degradation can be observed if the traffic is split over two adjacent channels and a further degradation if all nodes transmit in one channel. The impact starts to be relevant in the case of EIRP equal to 33 dBm, which corresponds to a CBR between 0,15 and 0,2 in the reference channel when the traffic is split into two channels (solid curves) and 0,333 when it is all in one channel (dashed curve). In such a case, some degradation is observed using the 1st adjacent channel and 40 % loss of range is noted when all the traffic is in one channel.

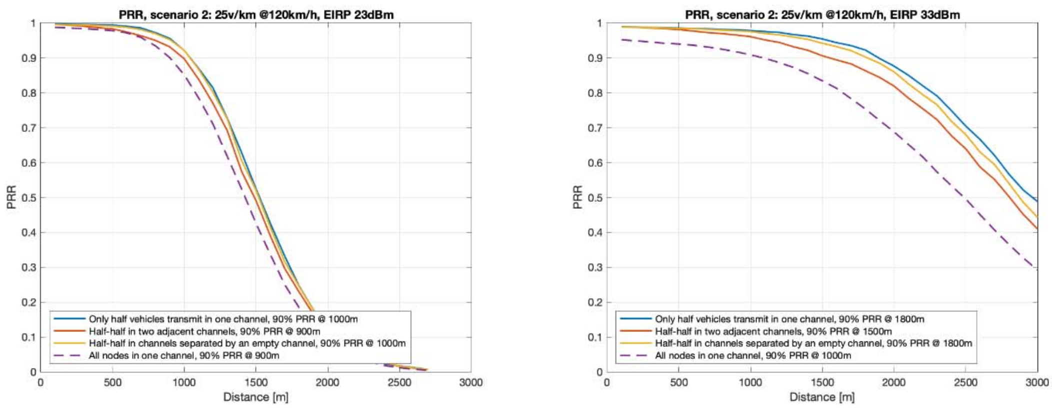


Figure 24: PRR vs. distance in scenario 2 with balanced traffic

In Figure 25, Figure 26, and Figure 27, the PRR versus distance is shown with reference to scenarios 3, 4, and 5, respectively. All curves coherently show that the impact of an interference from the 2nd adjacent channel is marginal, whereas the interference from the 1st adjacent channel has some impact. An exception is scenario 5 with EIRP = 33 dBm, due to the fact that DCC is triggered in that case and thus less messages are sent when the 1st adjacent channel is used. It is also confirmed that in all scenarios it is always better in terms of PRR to distribute the traffic over the channels, even if the 1st adjacent channel is used, instead of having all the nodes using the same channel. Specifically, if PRR = 0,9 is targeted, 20-25 % reduction is observed in the worst cases adopting the 1st adjacent channel, whereas the reduction is always larger than 50 % if all nodes use the same channel.

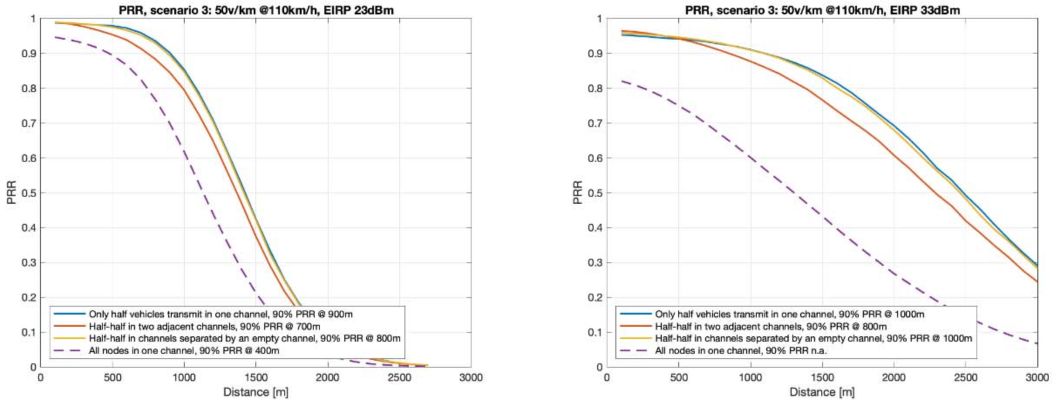


Figure 25: PRR vs. distance in scenario 3 with balanced traffic

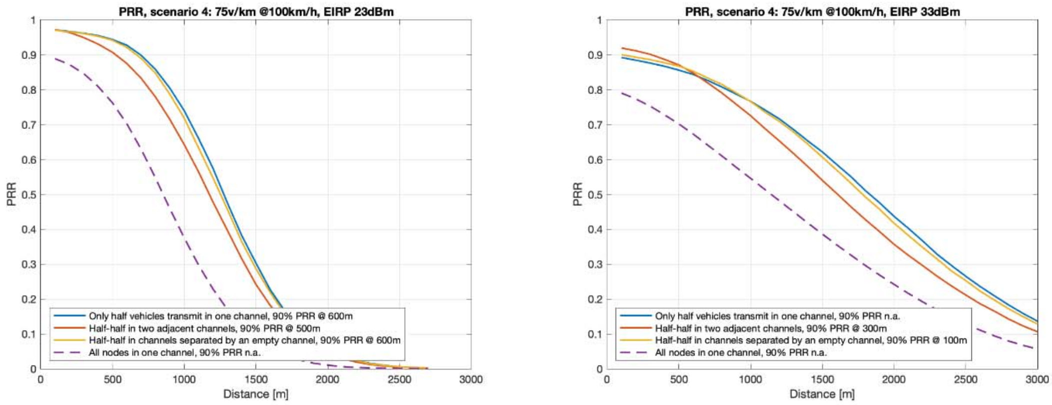


Figure 26: PRR vs. distance in scenario 4 with balanced traffic

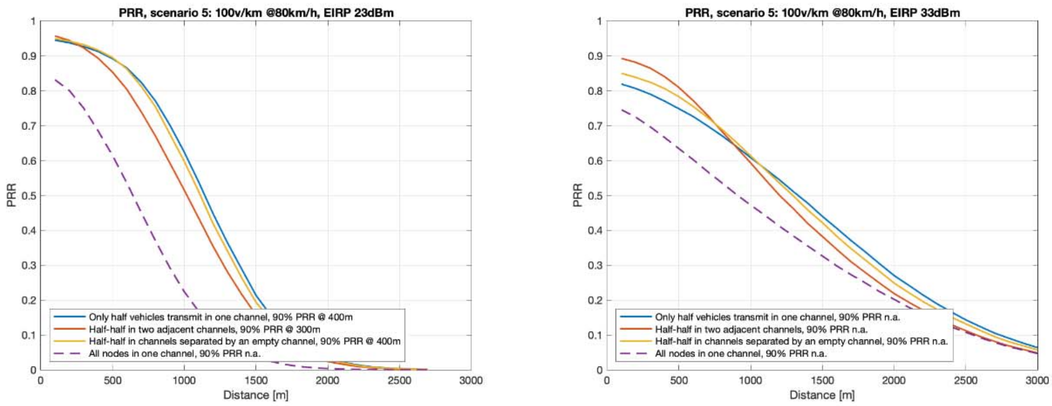


Figure 27: PRR vs. distance in scenario 5 with balanced traffic

8.5.2.5 Range and IPG

Hereafter, results under the same conditions are provided in terms of range and IPG.

Specifically, Figure 28 shows the range in all scenarios and under the various conditions. The values presented in Figure 28 correspond to those derived at PRR = 0,9 within the curves of PRR versus distance and are also reported in the legends from Figure 23 to Figure 27.

The results basically summarize what observed from Figure 23 to Figure 27. Please note that in some cases the range is zero as the PRR is always below 0,9 and that in scenario 4 with EIRP = 33 dBm the results shown in Figure 28 are not reliable, since in that case the curves corresponding to PRR versus distance have a maximum near to 0,9 (minor statistical variations cause large differences in terms of range).

Again, it can be observed that:

i) all cases perform similarly under light data traffic conditions;

ii) the impact of interference from the 2nd channel is very limited;

iii) the impact of the interference from the 1st adjacent channel has a non-negligible impact; and

iv) it is better to distribute the traffic over two adjacent channels instead of letting all nodes using the same channel.

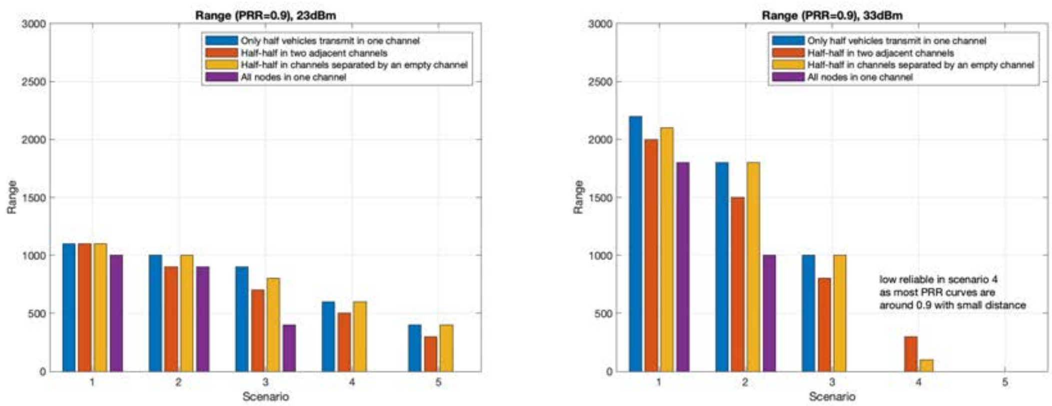


Figure 28: Range (maximum distance with PRR = 0,9) with balanced traffic

In Figure 29, the value of the IPG corresponding to its ccdf equal to 0,01 is shown. In other words, the reported values correspond to the IPG that is exceeded in the 1 % of cases.

In terms of IPG, some effect is visible only in the case of all nodes using the same channel, meaning that the interference from adjacent channels is not causing major effects on the correlation among errors.

The detailed curves, including the entire ccdf of the IPG for all simulations, are reported in clause E.2.

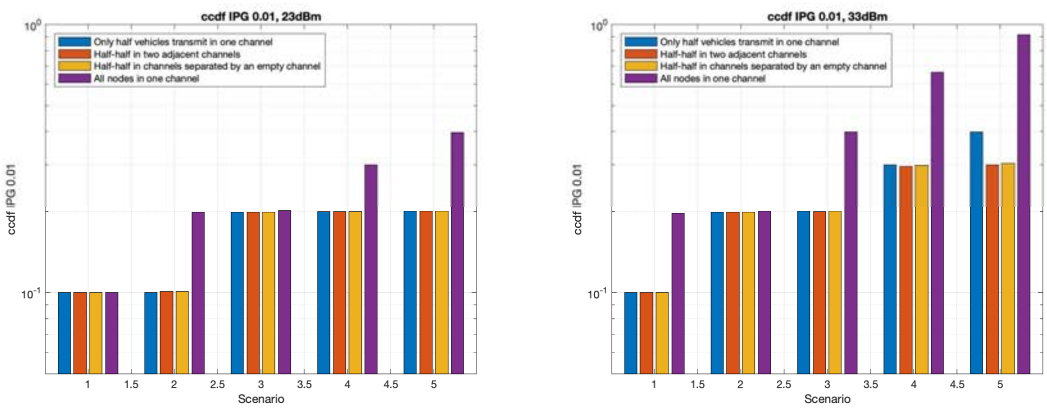


Figure 29: IPG exceeded with probability 0,01 with balanced traffic

8.5.2.6 Deriving conclusions in the balanced traffic case

The main observations following the results obtained in the balanced traffic case are hereafter summarized.

OBSERVATION: Interference from 2nd (and thus farther) adjacent channels can be neglected.

OBSERVATION: Interference from the 1st adjacent channel has little impact on CCA assessment but affects DCC measurements and overall performance (negligible only if the channels are lightly loaded); the range loss is minor if the channel is lightly loaded and can reach 20-25 % when the channel is highly loaded.

OBSERVATION: Distributing the traffic over two adjacent channels is always better than all the traffic in just one; the difference is remarkable, also compared to the use of two adjacent channels.

8.5.3 Imbalanced data traffic in adjacent channels

8.5.3.1 Introduction

Given the settings detailed in clauses 8.3 and 8.4, in this clause simulation results are provided assuming five scenarios, as detailed in clause 8.5.3.2. Data traffic is here assumed distributed over a reference channel and the 1st adjacent channel, either evenly (on average) or not.

8.5.3.2 Scenarios for the investigation in imbalanced traffic

In this case, five scenarios with a given density in the reference scenarios are considered and per each of them different densities are assumed in the 1st adjacent channel.

Specifically, the following five scenarios with different density and average vehicle speed in the reference channel are considered, which are consistent with those of the balanced traffic case detailed in clause 8.5.2.2.

- Scenario 1: half of 12,5 vehicles/km at 130 km/h in the reference channel.
- Scenario 2: half of 25 vehicles/km at 120 km/h in the reference channel.
- Scenario 3: half of 50 vehicles/km at 110 km/h in the reference channel.
- Scenario 4: half of 75 vehicles/km at 100 km/h in the reference channel.
- Scenario 5: half of 100 vehicles/km at 80 km/h in the reference channel.

Per each of the listed scenarios, the following densities are assumed in the 1st adjacent channel, with the same average speed of the reference channel.

- No data traffic, i.e. no active vehicles (this case was also considered in the balanced traffic investigation).
- Half of the vehicle density compared to the reference channel.
- Same vehicle density compared to the reference channel (this case means balanced traffic over two strictly adjacent channels, also considered in the balanced traffic investigation).
- One and a half times the vehicle density compared to the reference channel.
- Double of the vehicle density compared to the reference channel.

In Figure 30 the average speed and density that correspond to the listed cases is shown. The values adopted in the simulations are compared to what derives from the Van Aerde model [i.111] considering a maximum capacity of 2 200 vehicles per hour (achieved at 50 km/h), a maximum speed of 140 km/h, and a maximum density of 200 vehicles per km (traffic jam). The horizontal dotted lines link with each other the various cases investigated in the same scenario.

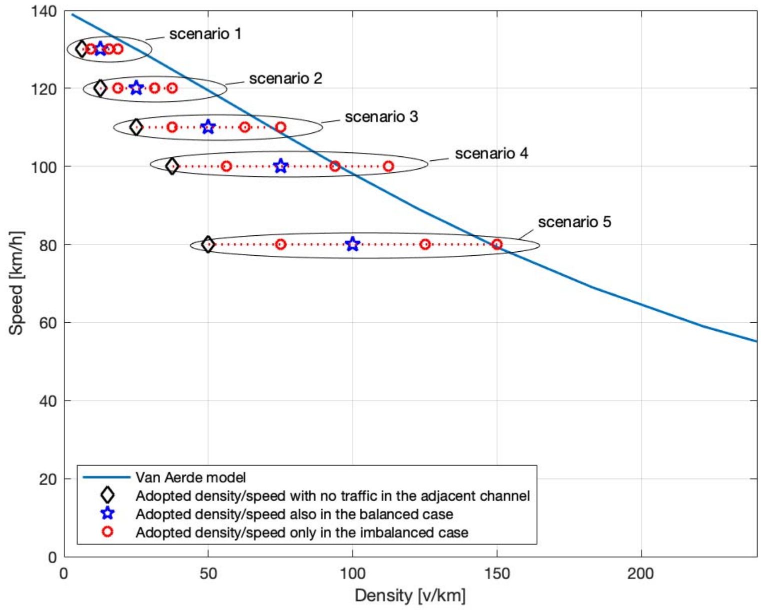


Figure 30: Speed vs. Density of the scenarios investigated in the imbalanced traffic case

8.5.3.3 Preliminary considerations

In Table 20, preliminary considerations on the simulated scenarios are provided. Per each vehicle density and both EIRP values (23 dBm and 33 dBm), the following metrics are shown:

- The "in CBR-range, reference channel", which counts, for a generic vehicle in the reference channel, the average number of neighbouring vehicles in the same channel which are sensed above the CBR threshold of -85 dBm during transmissions.
- The "median CBR in the reference channel (simulated)", which provides the minimum and maximum values of the median CBR obtained in the various cases by nodes in the reference channel; specifically, the minimum corresponds to the case with no traffic in the adjacent channel and the maximum to the one with double the density in the adjacent channel.
- The "maximum median CBR in the adjacent channel (simulated)", which provides the maximum values of the median CBR obtained in the various cases by nodes in the adjacent channel; when focusing on the adjacent channel, the minimum value is zero, corresponding to the case with no traffic in it.

In Table 20, the cases where DCC is triggered are marked with an asterisk. As observable, this happens when EIRP =33 dBm, inside the reference channel in scenario 5 and inside the adjacent channel from scenario 3 to 5.

Table 20: Preliminary considerations about the scenarios with imbalanced traffic. (*DCC active)

	EIRP 23 dBm In CBR-range, reference channel	Median CBR in the reference channel (sim)	Maximum median CBR in the adjacent channel (sim)	EIRP 33 dBm In CBR-range, reference channel	Median CBR in the reference channel (sim)	Maximum median CBR in the adjacent channel (sim)
Scenario 1 (half of 12,5 v/km)	6,9 vehicles	0,046-0,056	0,093	13,9 vehicles	0,087-0,099	0,175
Scenario 2 (half of 25 v/km)	13,8 vehicles	0,087-0,107	0,185	27,8 vehicles	0,169-0,194	0,351
Scenario 3 (half of 50 v/km)	27,7 vehicles	0,177-0,212	0,358	55,7 vehicles	0,333-0,374	0,593*
Scenario 4 (half of 75 v/km)	41,4 vehicles	0,264-0,311	0,514	83,5 vehicles	0,486-0,517	0,593*
Scenario 5 (half of 100 v/km)	55,4 vehicles	0,343-0,395	0,603	111,4 vehicles	0,585-0,600*	0,591*

8.5.3.4 PRR versus distance

Results in terms of PRR are shown for the imbalanced traffic from Figure 31 to Figure 35. In each figure, two plots are shown, referring to EIRP = 23 dBm and 33 dBm, respectively. In each plot, five curves are compared:

- No data traffic, i.e. no active vehicles (this case was also considered in the balanced traffic investigation).
- Half of the vehicle density compared to the reference channel.
- Same vehicle density compared to the reference channel (this case means balanced traffic over two strictly adjacent channels).
- One and a half times the vehicle density compared to the reference channel.
- Double of the vehicle density compared to the reference channel.

In Figure 31, the PRR versus distance is shown with reference to scenario 1. In this case, the channel is lightly loaded and the loss in terms of PRR is limited. Comparing the worst case, with double density in the adjacent traffic, to the best case, with no traffic in the adjacent channel, the difference in terms of distance at PRR = 0,9 is approximately of 10 %.

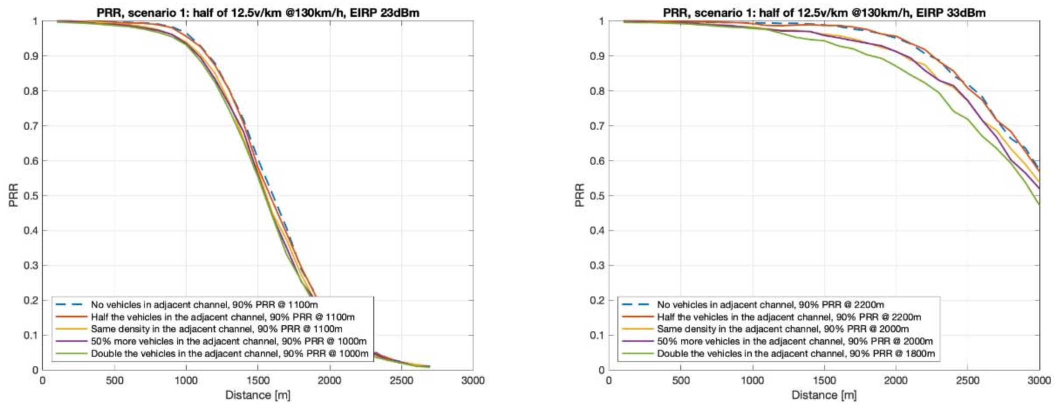


Figure 31 PRR vs. distance in scenario 1 with imbalanced traffic

Figure 32, Figure 33 and Figure 34 refer to scenarios 2, 3, and 4 respectively. As observable, the load in the channel progressively increases and the impact of the adjacent channel also increases. In these cases, the comparison between the worst case (double density in the adjacent channel) and absence of traffic in the adjacent channel reveals a reduction of the distance at PRR = 0,9 approximately between 20 % and 40 %. To be noted that, even if the impact of the interference in the adjacent channel is not negligible, it does not appear to prevent by using the reference channel neither in the worst case. It is also to remark that in scenarios 3 and 4 with EIRP = 33 dBm, the cases with higher traffic in the adjacent channel cause the triggering of DCC, meaning that the adjacent channel is already loaded at its maximum. This effect is particularly visible in scenario 4, where the DCC causes the cases with same or more transmitting vehicles in the adjacent channel than in the reference channel to behave very similarly.

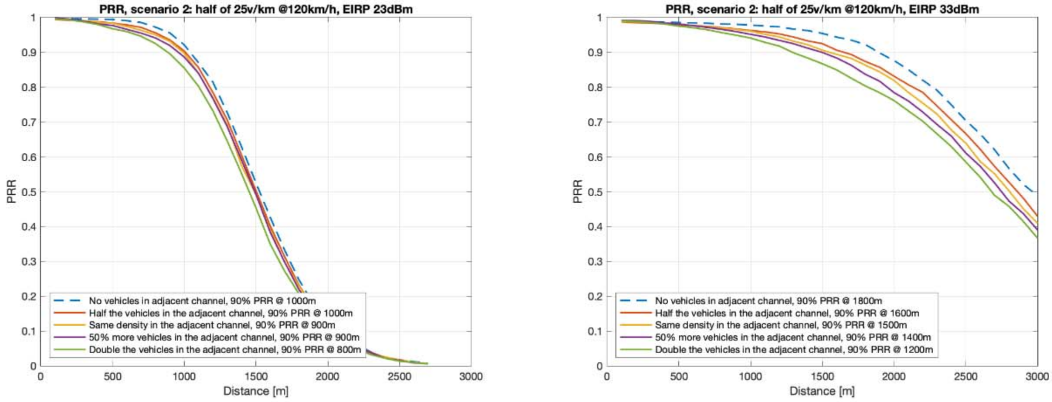


Figure 32: PRR vs. distance in scenario 2 with imbalanced traffic

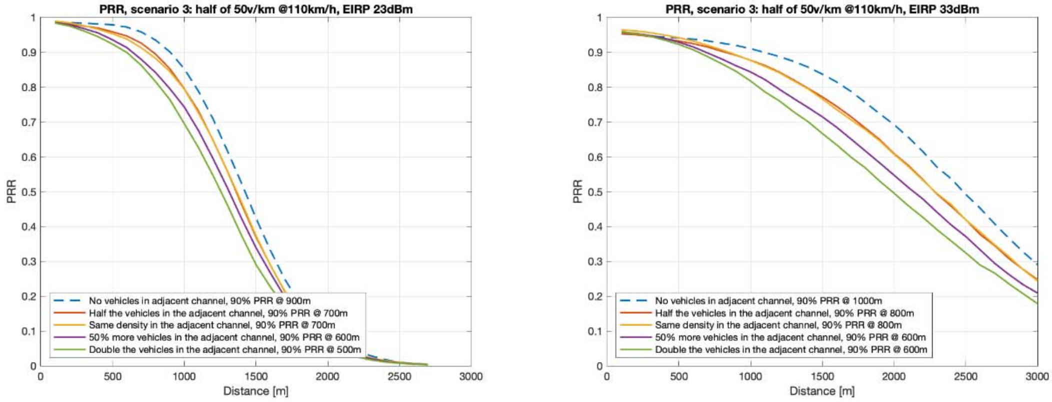


Figure 33: PRR vs. distance in scenario 3 with imbalanced traffic

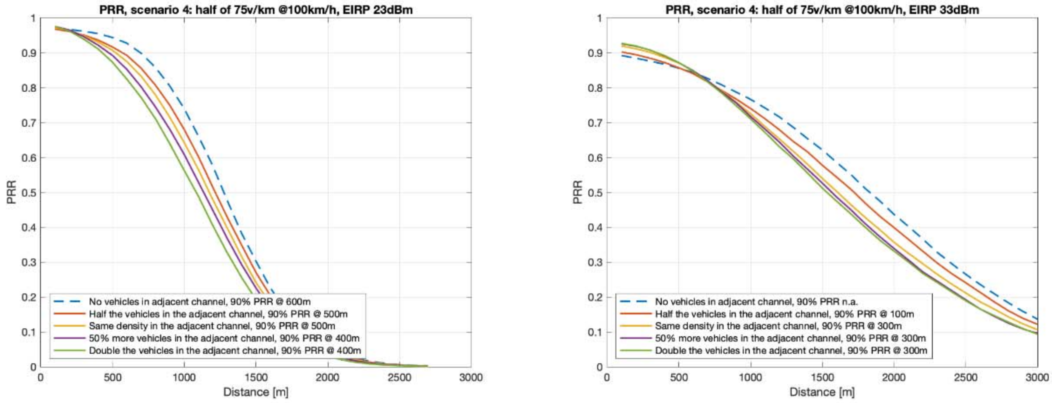


Figure 34: PRR vs. distance in scenario 4 with imbalanced traffic

Scenario 5 is finally addressed by Figure 35. In this scenario and referring to EIRP = 33 dBm, results are strongly affected by the behavior of DCC, which is triggered in the reference channel. In particular, an increase of the traffic in the adjacent channel causes an increase of the time when the nodes in the reference channel sense the channel as busy due to interference from the adjacent channel. This implies an indirect reduction of the time available for transmissions in the reference channel itself. The effect is that an increase of the traffic in the adjacent channel causes a reduction of the traffic in the reference channel, which on its own allows a slight improvement in terms of PRR at small distance in the reference channel.

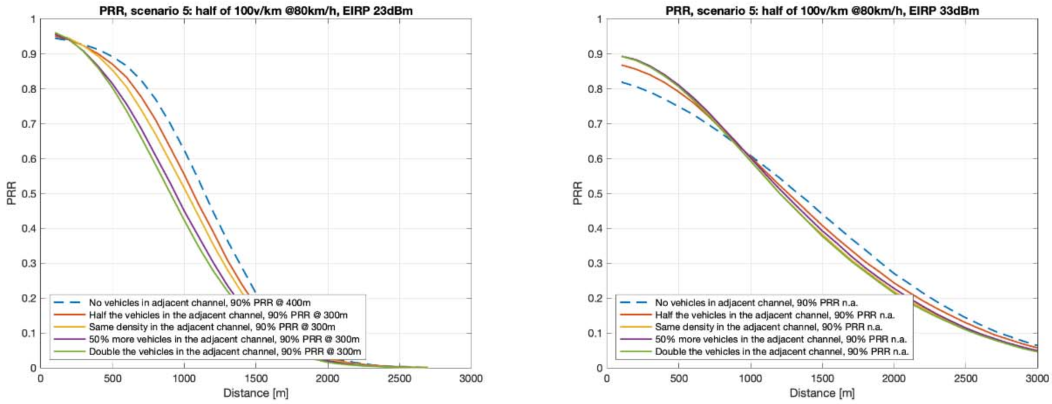


Figure 35: PRR vs. distance in scenario 5 with imbalanced traffic

8.5.3.5 Range and IPG

Hereafter, results under the same conditions are provided in terms of range and IPG in the reference channel.

Specifically, Figure 36 shows the range in all scenarios and under the various conditions. The values presented in Figure 36 correspond to those derived at PRR = 0,9 within the curves of PRR versus distance and are also reported in the legends from Figure 31 to Figure 35.

As observable and expected, in general the range of the reference channel reduces with an increase of the traffic in the adjacent channel. The reduction is more visible when the traffic is higher in the reference channel. As already discussed in clause 8.5.3.4, this behaviour is not observable only in scenarios 4 and 5 with EIRP = 33 dBm, in which DCC is triggered; indeed, in those cases the increase in number of the vehicles transmitting in either channel does not imply an increase in the channel occupation of the same channel.

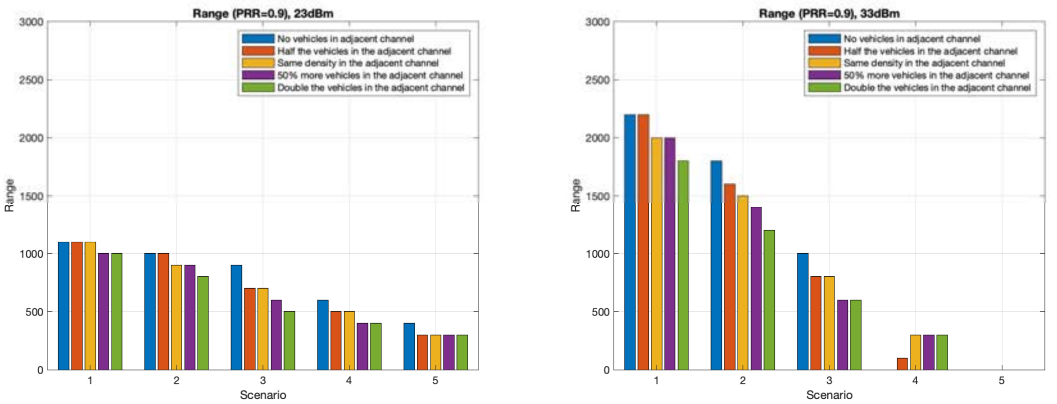


Figure 36: Range (maximum distance with PRR = 0,9) with imbalanced traffic

In Figure 37, the value of the IPG corresponding to its ccdf equal to 0,01 is shown. In other words, the reported values correspond to the IPG that is exceeded in the 1 % of cases. As observable, minor effects due to interference in the adjacent channel are visible from this point of view. This confirms that the presence of interference from the adjacent channel does not prevent from using the reference channel, neither in the case the adjacent channel is heavily loaded.

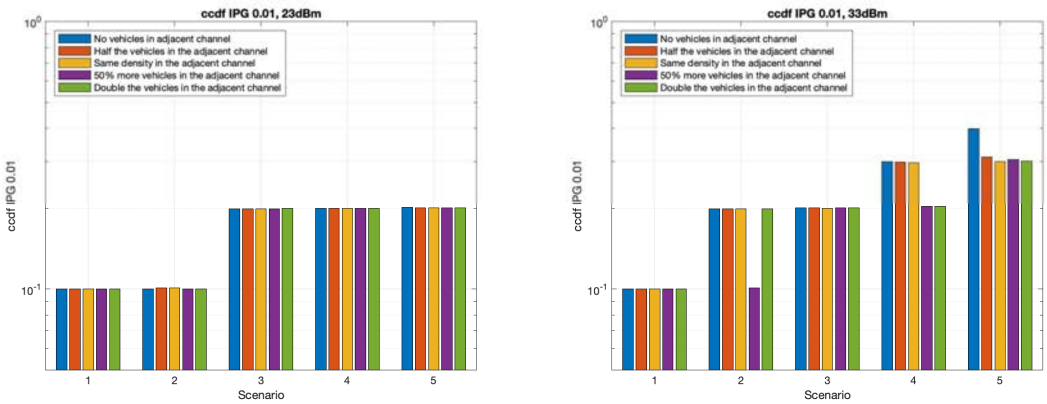


Figure 37: IPG exceeded with probability 0,01 with imbalanced traffic

8.5.3.6 Deriving conclusions in the imbalanced traffic case

The main observations following the results obtained in the imbalanced traffic case are hereafter summarized.

OBSERVATION: When DCC is not triggered, the interference from the first adjacent channel affects the performance of the reference channel. The impact is higher if more traffic is present in the reference channel.

OBSERVATION: The interference from the first adjacent channel impacts on the channel busy ratio. This implies that when the first adjacent channel is highly loaded, less data traffic can be transmitted in the reference channel.

OBSERVATION: The impact of the interference from the first adjacent channel does not appear to prevent from using the reference channel, neither when the adjacent channel is highly loaded.

8.5.4 Effectiveness of power and channel occupation control for MCO

From the technical aspects discussed in clause 7.5 and the results provided in this clause we can infer which is the expected impact of power and channel occupation variations in one channel to the performance of adjacent channels. In all cases, the impact is very limited focusing on the 2nd or further adjacent channel and thus only the 1st adjacent channel is referred hereafter.

Focusing on the power, it is observed in clause 7.5 that the interference is mainly due to adjacent channel leakage of the transmitter and adjacent channel selectivity of the receiver. With reference to ITS-G5 and following the calculations detailed in Annex A, the interference caused by a signal in the 1st adjacent channel to the reference channel is shown in Figure 38, assuming a receiver co-located with the transmitter (i.e. without considering the impact of the channel). As observable, with a variation of the EIRP in the adjacent channel from 0 dBm to 33 dBm, the variability of the interference in the reference channel is limited to about 4,5 dB. This limited variability implies that a limitation of the transmission power in one channel does not appear effective to reduce the interference over the adjacent channels.

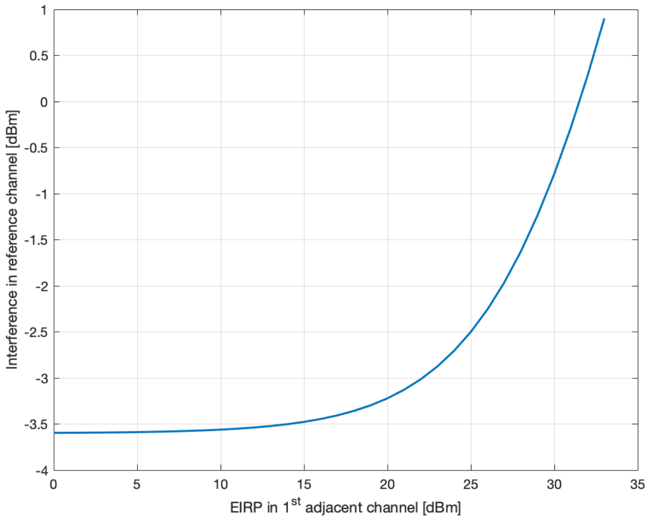


Figure 38: ITS-G5; Interference power by a signal in an adjacent channel to a reference channel, varying the transmission EIRP, assuming the receiver is co-located with the transmitter

Focusing on channel occupations and ITS-G5, the impact of variations of channel load in the adjacent channel to the reference channel can be inferred by the results shown in clause 8.5.3. As observed, a reduction of the channel load in one channel indeed brings to an improvement of the PRR in the reference channel. This eventually means that constrains to the channel load in adjacent channels can be indeed used to limit the impact over the reference channel.

OBSERVATION: In ITS-G5, given the current regulations on spectrum usage, controlling the transmission power in one channel does not appear as an effective approach to reduce its impact on the performance of adjacent channels.

OBSERVATION: In ITS-G5, controlling the channel load in one channel might be an effective approach to reduce the overall impact of interference from that channel on the performance of adjacent channels.

8.6 Summary

In this clause, the impact of interference from adjacent channels 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.

The results shown remark that distributing the traffic over multiple channels allows to overall improve the performance in terms of packet reception ratio and range. Whereas the use of the 2nd or farther adjacent channel has negligible impact, the use of the 1st adjacent channel is shown to cause some interference, reducing the reliability of the communications and altering the DCC effects (through an increase of the measured CBR). Still, the impact from the 1st channel appears limited and it is preferable to distribute the data traffic over two adjacent channels than maintaining it in a single channel. It is also shown that controlling the maximum channel load can be an effective approach to reduce the impact of interference from that channel to the adjacent channels. Differently, it was observed that controlling the transmission power has limited impact from the MCO perspective (which does not mean that it is not effective for other purposes outside the scope of MCO).

Obviously, these observations need to be considered jointly with the other limitations, such as, for example, the impossibility of some nodes to receive messages at the same time from all channels.

9 Multi-Channel Operation

9.1 Introduction

The Release 1 message triggering requirements can be supported by a single radio channel implementation. The Release 2 message triggering requirements are currently being developed showing additional communication requirements ensuring C-ITS backward compatible resource allocation over the additional channels. Release 2 basic communication requirements and technical capabilities are captured in clauses 5, 6, and 7. Moreover, clause 8 introduces additional flexibilities and limitations. Based on these findings, in the following clauses possible MCO mechanisms, policies and elements are identified and an MCO concept is proposed.

9.2 Physical channels

In spectrum regulation (clause 5.2.3) there is no direct physical (fixed) numbering identified, however IEEE identified channel numbering [i.100] for RLAN also for the C-ITS spectrum. This numbering should therefore be used for MCO. See Figure 39.

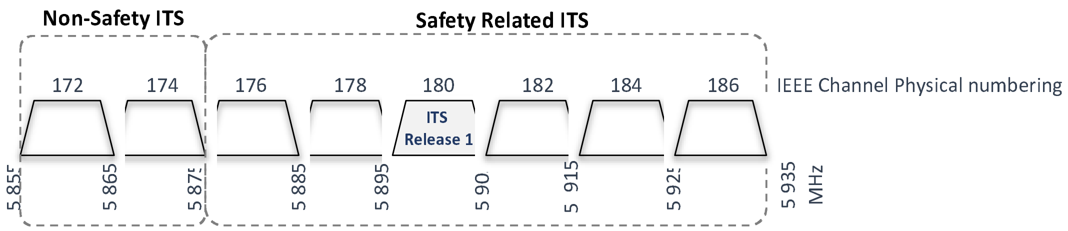


Figure 39: IEEE RLAN channel numbering [i.100]

9.3 Taxonomy of MCO possibilities

9.3.1 Introduction

In the following clauses, different possible approaches for MCO are reviewed and classified.

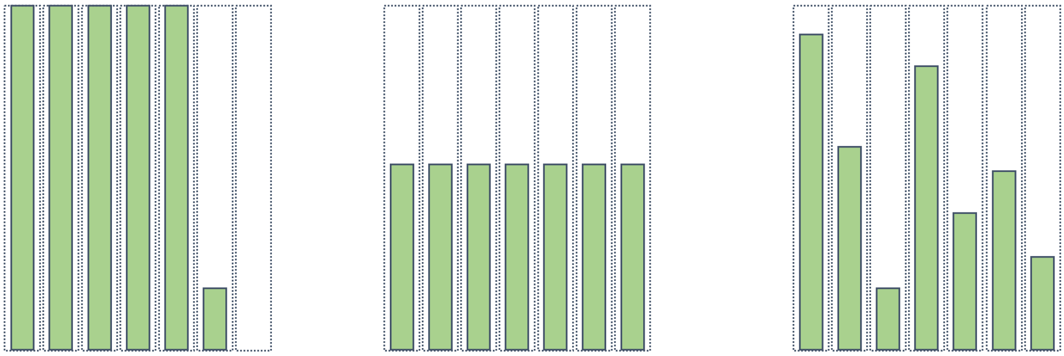
9.3.2 Channel usage mechanisms for MCO

Existing channel usage mechanisms for MCO can be classified depending on how the different channels are used and how the load is distributed. They are classified in the present document in 3 categories: *sequential filling, load balancing* and *elastic*. Figure 40 illustrates this classification with 3 examples. In this figure, each dashed rectangle represents one channel. The height of each dashed rectangle represents the channel capacity. The green rectangles represent the channel load on each channel.

The mechanism of *sequential filling* organizes the channels in a predefined order and a given channel is not used until the prior order channels are not loaded enough. This is illustrated in Figure 40(a) where 5 channels are fully used, 1 channel is partly used and 1 channel is not used, as an example. This MCO mechanism is partially considered in ETSI TS 102 724 [i.85], which is described in detail in clause C.1.

The mechanism of *load balancing* distributes the load among the different channels. This is illustrated in Figure 40(b) where the 7 channels are uniformly loaded. With this MCO mechanism, the channel load in the different channels is similar. This MCO mechanism is considered in CARHet [i.28] as described in clause C.2 and LTE-V2X RB allocation [i.112] and [i.99] as described in clause C.3. It is also partly considered by SAMCO [i.27], described in C.4, since it selects the channel with the lowest load but with some restrictions.

The *elastic* mechanism, in contrary to the two other mechanisms, does not specify how the load should be distributed among the channels. This mechanism is illustrated in Figure 40(c), where the load in the different channels is not uniform. A particular implementation of this MCO mechanism is known as SAMCO [i.27] and is described in clause C.4. Different channel usage mechanisms can be applied to different C-ITS services.



(a) Sequential filling (b) Load balancing (c) Elastic

Figure 40: Channel usage mechanisms for MCO

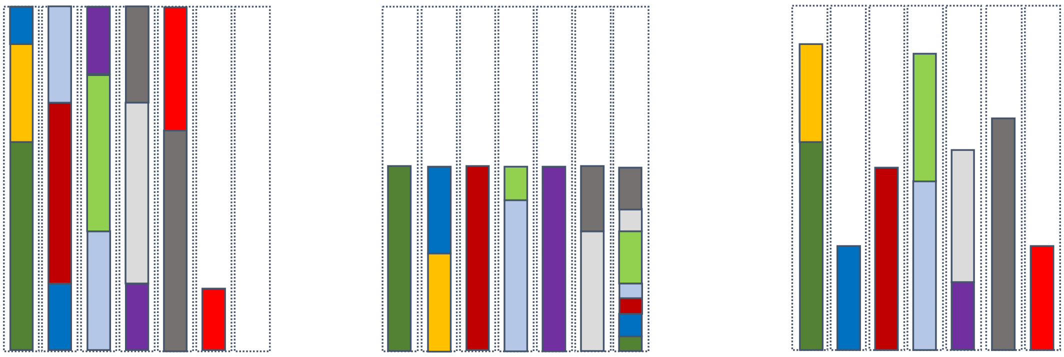
9.3.3 Channel association policies for MCO

Association policies for MCO can be classified depending on how each application or awareness service associates its messages to a channel for the transmission. As discussed in clause 5.5.4, the transmission of messages is triggered by applications or awareness services. Each application (not an awareness service) can make use of multiple message types (each of them generated by a different message service). Multiple applications can make use of the same message services. Therefore, the association can be defined by the triggering applications.

Two policies are currently identified, *predefined association* and *flexible association*. These associations are illustrated in Figure 41 and Figure 42, where each colour represents the load triggered by a different application or awareness service. Each type of association can be combined with any channel usage mechanism as described in clause 9.3.2.

Predefined association policies describe predefined rules, including the channel selection, by which applications and awareness services have to associate their messages. Thanks to these predefined policies receiving C-ITS-Ss know the channel(s) on which the messages can be received. Figure 41 illustrates the mechanism of *predefined association*, when combined with the *sequential filling*, *load balancing* and *elastic* mechanisms by means of a fixed message ordering. Each colour represents a different message type triggered by an application or awareness service.

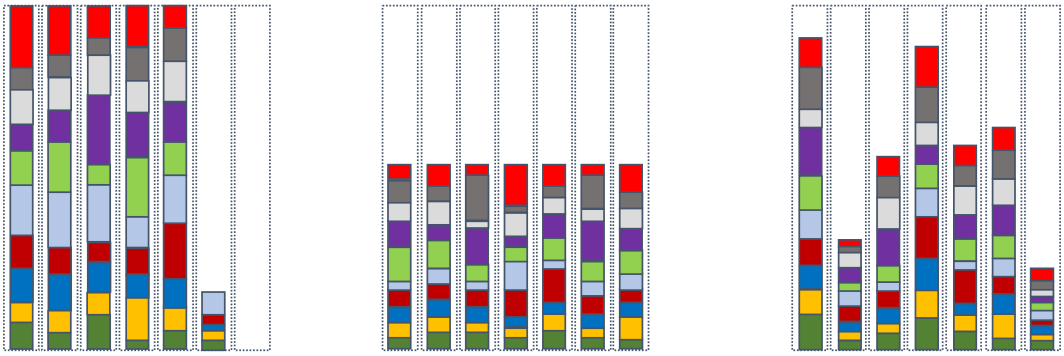
For Release 1, there was only a single channel, and thus no channel management was required. Therefore, messages could be directly sent down to the Transport & Networking layer by the message service. In particular, for Release 1 there is a *predefined association* policy with *sequential filling* defined in ETSI TS 102 724 [i.85] (see clause C.1 for details) based on DCC Profiles. With this policy, the messages are served in order based on a fixed assignment, since each message is associated to a DCC Profile. For Release 1, the access to the channel is only managed by congestion control mechanisms. In case of Release 2, more than one channel can be used. With a *predefined association* policy with *sequential filling*, if all initiated message transmissions do not fit on one channel, they will have to be transmitted in the next available channel. Moreover, when a message transmission is discontinued in a lower ordered channel, messages expected to be transmitted in a higher ordered channel could then be transmitted in a lower ordered channel and free up bandwidth in the higher ordered channels. When *predefined association* is combined with *load balancing*, it may be difficult that the channel load generated by the applications or awareness services is uniformly distributed, since the message association is predefined. Therefore, *predefined association* policies for *load balancing* might require the use of one (or more) channels to accommodate the channel load surplus on the other channels to achieve a homogenous channel load distribution. This is represented in the rightmost channel in Figure 41(b). *Predefined association* policies for *elastic* load distribution is achieved when the messages of each application or awareness service are associated with a predefined channel or set of channels. Multiple applications and awareness services could use the same channel for their message transmissions. Depending on the conditions, the channel load might differ from one channel to another, as illustrated in Figure 41(c). Channel sharing policies are needed to avoid exceeding the maximum channel capacity and realize robust operation of the applications. Additionally, it is required to manage the adjacent channel interference. Channel sharing policies are also considered in SAE J2945/0 [i.114] and the channel usage recommendation is provided to guide how to use the channels in 5,850 to 5,925 GHz frequency band in US for specific applications. For example, the Basic Safety Message (BSM, an awareness service) is recommended to associates its messages to channel 172, and the RoadSide Alert (RSA) is recommended to be used in the channels 178 and 184.



(a) Sequential filling (b) Load balancing (c) Elastic

Figure 41: Channel association policies for MCO: Predefined message association

Flexible association allows any application or awareness service to decide itself what channel to use for its message transmission. Still the C-ITS-S consuming applications need to know on which channel the messages can be received. Flexible association policies can be combined with the channel usage mechanisms described in clause 9.3.2, i.e. *sequential filling*, *load balancing* and *elastic*. *Flexible association* policies combined with the *sequential filling* mechanism let the applications and awareness services to decide the channel to use, but following the restrictions of sequential filling (i.e. the next channel cannot be used if the previous one is not fully loaded). This is shown with an example in Figure 42(a). In this example, a new C-ITS-S can select channels 1 to 6 to transmit but cannot transmit in channel 7 (rightmost channel in the figure) because channel 6 is not totally full. With the combination of *flexible association* and *load balancing* mechanism, each channel accommodates different applications or awareness services, and each application or awareness service consumes a different number of resources in each channel. This is illustrated in Figure 42(b) and is aligned to the mechanism defined in CARHet [i.28] (see clause C.2 for details). *Flexible association* policies for the *elastic* mechanisms results in dynamic and adaptable solutions. This solution is depicted in Figure 42(c) and is less focused on having a certain distribution of the channel load. Instead, it can provide (nearly) full flexibility to C-ITS-S to select the channel(s) to use. This solution is aligned with SAMCO [i.27] (see clause C.4 for details).



(a) Sequential filling (b) Load balancing (c) Elastic

Figure 42: Channel association policies for MCO: *flexible* message association.

Different channel association policies can be applied by different C-ITS applications and awareness services.

9.3.4 Supplementary functional elements for MCO

The IEEE 1609.4-2016 Standard for WAVE [i.26] defines some additional mechanisms of relevance for the correct operation of a Multi-Channel Operational system (see clause C.5 for details).

Signaling: in some cases, the transmission of information about the channel(s) used by certain messages might be required by other C-ITS-Ss. This can be used for those cases where there is no predefined assignment and/or channel usage. Signaling mechanisms can therefore increase the flexibility and robustness of an MCO concept but will introduce transmission overhead.

Prioritization: An MCO concept should take into account the priority of the expected triggered message transmissions. Here the channel access priority and the channel selection priority can be differentiated. In a given channel, a message with higher channel access priority should have lower channel access delay than a message with lower channel access priority, i.e. lower waiting time between the packet generation time at the upper layers and the packet transmission time at the physical layer. The priority of the message could be adapted by the application or service triggering it. The prioritization of different messages is for Release 1 achieved with Enhanced Distributed Channel Access (EDCA) in ITS-G5 using four different traffic classes, each of them with different contention window boundaries and other parameters. The prioritization is especially necessary for the situations in which the channel resources are not enough (channel overload). In a multi-channel system, a message transmission initiated by an application or awareness service with higher channel selection priority should have higher rights to transmit a packet in a given channel when it is overloaded (i.e. higher priority to avoid that its packets are offloaded to a different channel). In case of a system based on sequential filling with predefined assignment, certain message transmissions initiated by applications or awareness services will have a higher channel selection priority than others. The message transmission initiated with the highest channel selection priority, will be the last ones to be offloaded from one channel to the next. In general, an MCO concept can be configured so that the channel access priority and the channel selection priority of a given application are equal. However, higher configuration flexibility is provided if they can be different, and if they can differ on a per-channel basis. For example, two messages could have the same priority to be transmitted on SCH0, but a different channel access priority (e.g. as imitated by CA and DEN). Also, the messages triggered by an application could have certain channel access and selection priorities in a channel, but different ones if they are offloaded to another channel. The question is how to identify the channel access and selection priorities for the configuration of the predefined or elastic channel associations. There are different ways to prioritize messages, for example based on safety criticality levels or by directly assigning a priority level to their corresponding application or awareness service. In any case, a prioritization based on safety impact needs to be considered. From the MCO concept point of view this is seen as a triggering consideration and therefore the responsibility of the triggering entity. MCO is only responsible for providing information to these entities to allow a predictable information exchange and therefore only can set some application and awareness services behavioural principles and provide a related interface to applications and awareness services.

In Release 1, for ITS-G5 based on the C2C-CC [i.45] profile and for LTE-V2X based on ETSI EN 303 613 [i.23], messages are prioritized in SCH0 and the mechanism are handled at the facilities layer and not at the application layer. Four levels have been defined (0 = highest priority) in the single SCH0 channel:

0. High prioritized DENM messages
1. Low prioritized DENM messages
2. CAM messages
3. Forwarded DENM and SPATEM, MAPEM and IVIM messages (the so called InfraMessages)

In an MCO environment, these priorities could be defined for each message type (i.e. independent of the channel they use) or they could be different on each channel (e.g. the message could have a priority 2 in SCH0, but a priority 1 on SCH1). Prioritization could be made dependent to the specific application or awareness service, or to the safety critically levels as defined by ISO 26262 [i.90] for other channels than SCH0.

Channel load information sharing: the limitations of C-ITS-S to locally measure the status of all the channels could require to cooperatively measure the channel load. C-ITS-S could exchange their channel load measurements to have an updated view of the status of all the channels. This mechanism was proposed and evaluated in [i.27] and [i.28]. It is particularly needed when the number of active channels in the MCO concept (i.e. the number of channels where messages are transmitted) is higher than the number of radio interfaces available in a given C-ITS-S. If the number of active channels and the number of radio interfaces are equal, the channel load can be directly measured and there is no need to exchange information about it.

Redundant transmissions: to overcome some limitations related to the fact that C-ITS-S may not be able to listen all the channels, the use of redundant transmissions (the same messages are sent in multiple channels) could be useful. This mechanism is also particularly useful for the dynamic and flexible MCO mechanisms previously described.

Guard channel: some channels might be used as guard channels to reduce adjacent channel interference.

9.4 MCO approaches

9.4.1 Introduction

Based on the identified requirements and the conducted analysis, the following clauses present the MCO approaches proposed.

9.4.2 C-ITS Channel use and relation

Message exchange between C-ITS stations can be realized via different channels, protocols and technologies. Messages should be transmitted on the best fitting channel. For Release 1 and Release 2 as also shown in Figure 43 the Logical and physical channels are directly linked. For later releases it could be considered that the relation between logical and physical channels is decoupled and that a facility entity manages the use of the non-directly linked channels transparently to the applications (virtually).

To allow future virtualization and layer independency, the logical and physical channel naming is separated. The Logical numbering is different from the ETSI EN 302 665 [i.8] as this has never been used while other naming has been often used in accordance with various documents and publications dealing with 5,9 GHz C-ITS and does not prevent the introduction of additional channels in the future.

The following logical numbering is based on the different spectrum regulations and their developments over the last 10 years:

- Physical channel 180 was chosen as the first one and was called control channel, thus numbered as SCH0.
- Physical channel 176 was chosen as second channel, since among the 3 earliest designated ITS safety channels it would interfere the first channel less than channel 178, thus numbered SCH1.
- Physical channel 178 is the last of the 3 designated ITS safety channels and therefore numbered as SCH2.
- Physical channels 174 and 172 have been designated as SCH3 and SCH4 because they were least important (non-safety) and they were the only other 2 channels available at the time C-ITS development started.
- Physical channels 182 and 184 were recognized but not designated in the beginning, and therefore given the highest numbers SCH5 and SCH6.
- Physical channel 186 is assigned as SCH7 as this is the last channel added.

In order to create ambiguity with older publications we therefore use the same logical channel naming and relation is used, with the physical layer numbering as provided in Figure 43.

When additional radio channels are available it will be possible for those channels to decouple the logical and physical numbering depending on the channel use strategies for those channels.

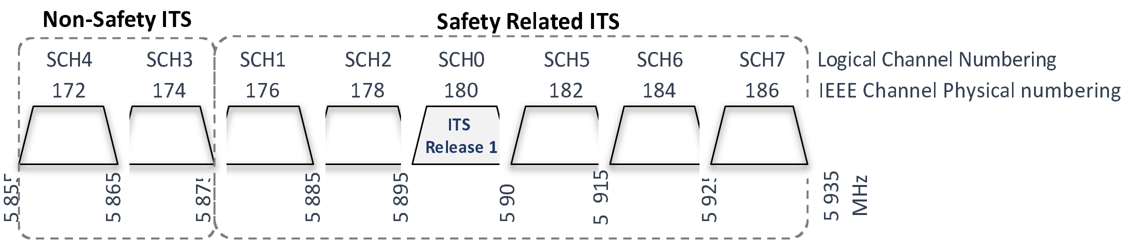


Figure 43: Functional and physical channel numbering of the C-ITS bands

NOTE: For the moment there is no channel assignment for the 63,72 GHz to 65,88 GHz band.

Based on the findings as identified in clause 8, it is suggested to recognize the channels 172, 176, 180 and 184 as the main channels using general access characteristics and the channels 174, 178, 182 and 186 as first adjacent channels which might require to follow more stringent channel load requirements as identified in clause 8 to ensure robust operation of an MCO concept in C-ITS. These more stringent values need to be further studied.

9.4.3 C-ITS Message classification

Three classes of messages are identified, which can be associated to different MCO strategies:

a) *Basic Broadcast*: broadcast messages to be transmitted by C-ITS-Ss realized based on Release 1 specifications identified in the ETSI TR 101 607 [i.25]. This class includes CAM, DENM, SPATEM, MAPEM, IVIM messages, exchanged by vehicle and infrastructure applications and awareness services covered by Release 1 profiles implemented today.

b) *Advanced Broadcast*: broadcast messages to be transmitted by C-ITS-S applications and awareness services that are not part of the Basic Broadcast under point a). This class includes the broadcast messages corresponding to the Release 2 and beyond applications and awareness services that are being defined or will be defined.

c) *Advanced Groupcast*: groupcast messages to be transmitted to a subset of C-ITS-Ss interested in participating in the operation of a specific application or awareness service, e.g. platooning, prioritization (public transport, emergency applications) and others.

9.4.4 Basic broadcast

The basic broadcast is specified by the Release 1 specifications. All Release 1 transmissions are broadcast and need to be transmitted in SCH0 to ensure backwards compatibility. Early analyses have shown that a single channel should be sufficient but in case full penetration is reached offloading mechanisms may need to be included in later Releases.

9.4.5 Advanced broadcast

9.4.5.1 Introduction

Sequential filling and elastic mechanisms are the two methods recommended to advanced broadcast. Load balancing is indeed only effective when the number of radio interfaces used is the same for all C-ITS-S active in the same ITS constellation. The best solution though depends on future deployment options (i.e. number of applications, awareness services, channels and interfaces available). Sequential filling and elastic filling allocation solutions could provide the best compromise between performance and complexity.

Predefined association policies are most applicable for advanced broadcast messages. Flexible association policies in fact cause significant communication overhead as the sourcing part of the application or awareness service triggering the message transmission needs to additionally inform the receiving part of the application how this can be expected to be done (something which needs to be predefined).

Load balancing is not considered for advanced broadcast.

9.4.5.2 Advanced broadcast using sequential filling with predefined association

When using a sequential filling assignment approach with predefined association, the following aspects should be considered:

1) Channel use ordering. Based on current spectrum regulation as identified in clause 5.2.3.
Use the channels in order of: SCH0, SCH1, SCH2, SCH5, SCH4, SCH3 for V2X and SCH6 only for I2V and testing in a predefined area non-interfering with Urban-Rail.

2) Predefined association. This approach requires the definition of an ordering to rank the messages triggered by applications and awareness services. When more than one channel is needed, messages with lower order will use SCH0 and messages with higher order will be offloaded to the next channel(s). Release 1 applications and awareness services should have the lowest order so that their messages are all transmitted in SCH0. To ensure C-ITS backward compatibility, the first 4 (from 0 to 3) are occupied by current high priority DENM, low priority DENM, CAM, and InfraMessages as identified in clause 9.4.3. As part of Release 2, CPM could be ordered as number 4 when this is commonly agreed. Higher numbers could be assigned to newer messages. Two or more messages triggered by different applications or awareness services could have the same ordering as long as evaluations show non-operational interference or are commonly managed. In such case they have equal rights to use a given channel (i.e. if they need to start using the next channel, they are all proportionally offloaded to the next channel). The ordering method is an applications principle. The ordering is equivalent to the channel selection priority defined in clause 9.3.4.

3) Because of C-ITS backward compatibility requirements, later identified messages will not be allowed to get an earlier order number then already assigned ones, unless certain numbers are not assigned and left for future use. In later releases, updated earlier entities which require additional message exchange need to consider the request for an additional order number not to influence the behaviour of the other applications.

4) Mechanisms need to be defined by which receiving stations can identify what applications or awareness services provides what information on what channel. This is particularly useful when the number of physically implemented radio interfaces is lower than the number of channels on which C-ITS data is shared.

5) All messages triggered by applications and awareness services also need to be mapped into a channel access priority. Such priority could be aligned with the channel selection priority that is used to order the entities for selecting their channel. This mapping is particularly important when the number of available channel selection priorities and the number of available channel access priorities are different. Messages could have a different channel access priority in different channels, so that a given message could have the lowest channel access priority in SCH0, but the highest one in SCH1, for example.

9.4.5.3 Advanced broadcast using an elastic mechanism with predefined association

Advanced broadcast message transmissions can be supported by an elastic assignment with or without offloading configuration. Each message triggered by application or awareness service selects one channel where the specific messages have to be transmitted (e.g. when the channel is not overloaded) and may select one or more offload channels in a predefined order. With this approach, each service is then associated to a sequence of channels (not necessarily the same sequence for all services). If all applications and awareness services are configured with the same default channel and the same predefined order for the offloading channels, that is equivalent to the one defined in clause 9.4.5.2 (sequential filling with predefined association). However, with a more general configuration, each application or awareness service would have a potentially different default channel and offloading channels, and then this approach would be equivalent to sequential filling with a different order per message.

When using an elastic assignment approach, the following aspects are considered.

1) Channel use

   a) Based on current spectrum regulation as identified in clause 5.2.3.
   Use the channels SCH0, SCH1, SCH2, SCH5, SCH4, SCH3 for V2X and SCH6 only for I2V and testing in a predefined area non-interfering with Urban-Rail.

   b) The channel use for Release 2 needs to ensure C-ITS backward compatible use of the channel by Release 1 applications.

2) Predefined association. A predefined channel is identified for each message triggered by an application or awareness service. Such configuration should at least include a default (or primary) channel, with a channel selection priority and a channel access priority. The channel selection priority ranks the applications based on their rights to use a given channel. The channel access priority defines their priority to access the radio channel. The configuration can additionally include possible secondary offloading channel(s) where its messages could be offloaded, as well as the corresponding offloading conditions.
For C-ITS-S backwards compatibility, messages triggered by Release 1 services should have SCH0 as predefined default channel.
A generalized ordering can be realized based on approaches such as individual application assessment, application or awareness service classification or safety critical level (ISO 26262 [i.90]) assessment.
An example including offloading parameters for messages triggered by applications and awareness services is provided in Tables 21. Table 21a shows how each message has a default channel and a sequence of channels to offload when previous channels are overloaded. Table 21b corresponds to the same example, but each row shows the messages with higher and lower channel selection priority to use each channel before being offloaded to the next channel.

Table 21a: Example of channel sequence definition for different Release 2 messages, channel sequence for each Release 2 message

Message	Default channel	First offload channel	Second offload channel	Third offload channel
DENM	SCH0			
CAM	SCH0	SCH1		
MAPEM	SCH0	SCH6		
SPATEM	SCH0	SCH6		
CPM	SCH1	SCH4	SCH6	SCH2
MCM	SCH4	SCH5	SCH3	SCH4
NOTE: For simplicity here all DENM and SPATEM messages are associated to a channel as if its generating awareness message services define the channel in which the messages need to be transmitted, while messages generated by the DEN or SPAT services could be transmitted in any channel for Release 2 applications.				

Table 21b: Example of channel sequence definition for different Release 2 messages, channel selection priorities

Channel	Message with highest priority	Message with second highest priority	Message with third highest priority	Message with fourth highest priority
SCH0	DENM	CAM	MAPEM + SPATEM	
SCH1	CPM	CAM		
SCH4	MCM	CPM		
SCH6	MAPEM + SPATEM	CPM		
SCH2	CPM			
SCH5	MCM			
SCH3	MCM			
NOTE: For simplicity here all DENM and SPATEM messages are associated to a channel as if its generating awareness message services define the channel in which the messages need to be transmitted, while messages generated by the DEN or SPAT services could be transmitted in any channel for Release 2 applications.				

3) For each channel, the channel access priority of each message generated by an application or awareness service needs to be defined. This priority is used to provide channel access differentiation (e.g. EDCA in ITS-G5 or PPPP in LTe-V2X). It could be the same priority than the one used to define which messages would be offloaded to the next channel in the sequence in case of channel overload. In the previous example, the priorities of CPM and MCM defined for SCH4 will influence on how they access the channel, and on which of them would be offloaded to the next channel (SCH6 in both channel sequences of CPS and MCS).

9.4.6 Advanced groupcast

9.4.6.1 Introduction

When predefined association is used for advanced groupcast, the advanced broadcast approach as described in clause 9.4.5 can be used and no specific considerations need to be added.

Specific considerations need to be introduced when flexible association is used. Given that only a selective set of C-ITS-S need to communicate, the flexible association appears in this case naturally linked with an elastic mechanism, whereas its use with sequential filling or load balancing appears not to be preferred.

9.4.6.2 Advanced groupcast using elastic with flexible association

Flexible association could help in the case of advanced groupcast to improve the channel usage. In the case of flexible associated groupcast, a negotiation between the interested C-ITS-S should lead to an agreement on which channel to exchange data. The negotiation can be between all equal parties or can be a negotiation with one or only several leaders. The negotiation mechanism is defined by the applications stakeholders and therefore application and service specific.

For the purpose of MCO it is only relevant to ensure that the channel use is predictable and manageable to ensure robust operation of the applications.

The following aspects are considered:

1) Channel use

   a) Based on current spectrum regulation as identified in clause 5.2.3.
   Use the channels SCH0, SCH1, SCH2, SCH5, SCH4, SCH3 for X2X and SCH6 only for I2V and testing in a predefined area non-interfering with Urban-Rail.

   b) The channel use for Release 2 needs to ensure C-ITS backward compatible use of the channel by Release 1 applications.

2) Flexible association
   When a C-ITS-S application or awareness service wants to initiate a user services, it needs to negotiate with interested C-ITS-Ss what channel to used. There are different negotiation mechanisms which can be defined for each applications or awareness services differently and have their own criteria to select a channel as long as the use of the channels is compliant with the channel load limits (e.g. the selection could depend on its number of radio interfaces, other active applications and services, channel load levels etc.). These limits can be set statically based on MCO applications policies and can be extended with predefined dynamic mechanisms realized as part of a MCO communication management functionality.

3) When the channel load on the selected channel increases, the MCO communication management entity could trigger a channel re-selection. Off-loading criteria could be defined as long as the defined channel load conditions are respected.

4) To inform other C-ITS-S about an active groupcast application or awareness service, the transmission of SAEMs could be used. Such SAEMs can be transmitted in an application/service specific channel, or in a predefined channel.

5) Advanced groupcasts are filling up the channels, therefore the priority of the messages as well as the related SAEMs need to be carefully assigned.

9.4.7 Evaluation of the pros and cons of sequential filling and elastic assignment for Advanced Broadcast

9.4.7.1 Introduction

For each application or awareness service message exchange, an MCO concept should support the requirements identified in the clauses 5 and 6, to realize a Release 2 system. Additionally, it is important to identify what mechanisms are most appropriate to realize an MCO concept in a predictable manner. In clause 9.4.7.2 the C-ITS interoperable criteria are identified. From the analyses of clauses 5 and 6 and 9.4.7.3 a comparison can be made between the sequential filling and elastic assignment for Advanced Broadcast.

9.4.7.2 Criteria

The following criteria are identified:

1) Predictable message reception: What is the level by which a receiving C-ITS-S application can be aware about the channel(s) on which relevant messages can be found?

2) Number of channels to implement: Each type of station (for a vehicle, truck, bus or pedestrian) makes use of different types of messages. What is the influence on the channel use of the mechanism for varying types of stations?

3) Concurrency with load balancing: What is the influence on the operation of applications operating based on the load balancing mechanism of the mechanism?

4) Extension of existing applications: What is the ability of the mechanism to support the extension of existing applications?

5) Introduction of new applications: What is the ability of the mechanism to support the addition of new applications?

6) Channel efficiency: How efficiently minimizes the mechanism the of channel usage for a given message transmission?

9.4.7.3 Comparison

This comparison compares the use of the sequential filling and application-based elastic assignment mechanisms for advanced broadcast. Table 22 provides an overview of the effects of these mechanisms on an MCO concept.

The values provided range from -5 to 5, in which -5 represent the worse impact and 5 the best influence.

Table 22: Pros and cons elastic filling and application-based elastic assignment

Evaluation Criteria		Sequential Filling Predefined		Elastic Filling Predefined	
Num.	Criteria	Value	Pro/Cons	Value	Pro/Cons
1	Predictable message receiption	1	The predictability of the reception is depending on the order of the message transmission, the lower the order the higher the predictability. This means that for CAM it is prity clear but for higher ordered message exchange it may even depend on several DCC channel values by which it is less clear.	3	For each application or awareness message exchange the channel characteristics are predefined. There is only dependency for lower prioritized messages to be dropped or be off-loaded when defined. In such cases disregaring or off-loading is well defined and could therefore only depends on specific single channel DCC settings.
2	Number of channels to implement	-3	The number of channels to be implemented depend on maximum order of the messages to be transmitted to facilitate all applications to be active in an C-ITS-S. The higher the order the more channels to be implemented despite that only higher order applications are active.	2	Only those channels to be implemented which are required for the operation of the applications active in a specific C-ITS-S.
3	Concurrency with load balancing	1	Can operate concurrently with load balancing supported application with lower priority for load balancing to ensure the applications to receive their messages in the expected range of channels. When in environment where the other services are operating very dynamically the use of channels by load balancing may be a challange.	3	Can operate concurrently with load balancing supported application with lower priority for load balancing to ensure the applications to receive their messages in the expected range of channels. When in environment where the other services are operating very dynamically these are specific for specific channels and therefore this mechanism has less impact on the operation of load balancing based applications.
4	Extending of existing applications	-3	In case the message exchange for an exisiting application or awarenes service changes significantly it is possible that the message exchange of higher ordered applications or awareness services is influenced. It is therefore required that such applications exchange the additional messages at an order higher than its orriginal message as it influences the operation of all other lower ordered applications.	-1	Extension of an existing applications or awareness service could have effect on existing but only in the same channel(s) it is active in and could be handled more easily by making use of offloading mechanisms.
5	Introduction of new services	-2	As long as there is no final congestion (over all channels used for sequential filling) the new service has to be added after the last ordered application. No other priorities can be used.	2	As it is known where existing services are active and how they perform, new applications can just be added without influencing others with large consequences.
6	Channel efficiency	5	Based on the ordering principle the channel use is most efficient	1	Based on the dynamic use of the different applications and awareness services, when fixed to specific channels, this will less channel efficiency.
Total Score		-1		10	

9.4.8 Advanced Considerations

9.4.8.1 Introduction

This clause includes additional considerations enabling a robust operation of C-ITS applications.

9.4.8.2 Transmit power

Based on the findings in clause 8 the contribution of transmit power to an MCO concept has no decisive impact. It however is useful to increase the capacity of the ad-hoc network and could be used as an application principle. Applications could be obliged to use a transmit power fitting the relevance area to be addressed.

9.4.8.3 Use of Non-Safety related channels SCH3 and SCH4

Based on the findings in clause 8 it can be concluded that it should be possible to use the SCH3 and SCH4 for C-ITS safety related information exchange under specific conditions. Clause 8 identifies that in the case that SRDs are used in buildings along the road, that the C-ITS message exchange is not significantly interfered by these transmitting SRDs. As only a basic case is analysed it is commended that further analyses identify the worst-case scenario(s) and the max area of relevance which could be set for the use by C-ITS safety related applications to use SCH3 and SCH4 without harfull interference.

9.4.8.4 Use of the announcement service for MCO

The SAS is a general C-ITS service which can be used by any C-ITS stakeholder or C-ITS-S to make users or other C-ITS-Ss aware of the presence of a specific user service. With Release 1 implementations SAS was not required to be used for safety related message exchange in the 5,9 GHz band as only 1 channel was used but when using multiple channels for the exchange of information it is important to agree on which channel and with what message priority (0-3) SAEMs will be shared so that any C-ITS-S knows where it can receive safety related or non-safety related SAEMs.

In clause 6.3.2 it is identified that any specific application can identify on what channel to exchange SAEMs and its other messages as long as that it does not influence the operation of existing applications. This is true for any specific application. Only for general C-ITS-S related user services as identified in clause 6.3.2.2 a general channel needs to be assigned. Based on the outcome of clause 6.3.2.3 the following recommendation can be made.

- C-ITS application can send application specific safety related SAEMs in any safety related channel as long as it is not in SCH0 and as long as the consuming part of the application is aware of where to receive the SAEMs.
- In case SCH0 is assigned as the safety related channel in which the generalized safety related SAEMs are sent, a C-ITS application can send application safety related SAEMs in SCH0 for those cases the consuming part of the application cannot be aware of where to receive the SAEMs.
- C-ITS application can send application specific non-safety related SAEMs in any non-safety related channel as long as the consuming part of the application is aware of where to receive the SAEMs.
- In case SCH4 is assigned as the non-safety related channel in which the generalized non-safety related SAEMs are sent, a C-ITS application can send application non-safety related SAEMs in SCH4 for those cases the consuming part of the application cannot be aware of where to receive the SAEMs.

9.4.9 MCO Architecture and its entities

In the clauses above mainly the applications and message related considerations have been addressed. In this clause the MCO architecture based on the reference architecture as provided by the ETSI EN 302 665 [i.8] is identified.

Figure 44 provides a proposed architecture in which the MCO_CROSS, MCO_FAC, MCO_NET and MCO_ACC entities are recognized.

Applications or awareness services trigger the message generation in the message generating services and provide all messages including their communication requirements to the MCO_FAC to distribute the messages to the appropriate channels.

The MCO_FAC is informed by MCO_CROSS how or under what rules the specific messages should be distributed.

To allow the MCO_CROSS to identify how or under which rules these messages should be distributed, applications and awareness services should register to the MCO_CROSS and provide their static and dynamic communication requirements to the MCO_CROSS entity. All MCO_NETs and all MCO_ACCs should register and provide their status and dynamic capabilities to the MCO_CROSS entity to make it aware of the static and dynamic state of the underlaying communication channels. To realize this, the following management interfaces are needed:

1) Interface between applications and MCO_CROSS for the registration, the communication requirements information exchange and the process management information exchange via the MA-SAP.

2) Interface between message services and MCO_CROSS for the registration, the capabilities information exchange, and the process management information exchange via the MF-SAP.

3) Interface between MCO_CROSS and MCO_FAC for setting up and controlling the MCO_FAC dataflow processes and error handling via the MF-SAP. This can be seen as the extension of the in Release 1 interface DCC_CROSS and DCC_FAC as defined in ETSI TS 103 175 [i.118].

4) Interface between MCO_CROSS and the channel specific MCO_NETs via the MN-SAP. This can be seen as the extension of the in Release 1 DCC_CROSS to DCC_NET interface as defined in ETSI TS 103 175 [i.118].

5) Interface between MCO_CROSS and the channel specific MCO_ACCs via the MI-SAP. This can be seen as the extension of the in Release 1 DCC_CROSS to DCC_ACC interface as defined in ETSI TS 103 175 [i.118].

Besides the management interfaces the following data flow interfaces should be used:

- As identified in the ETSI EN 302 665 [i.8], the FA-SAP is not used by MCO_FAC but is used by the applications to trigger the message generation as part of the data interface. An awareness services can use the same interface but does not need to use the FA-SAP as this is a facility service.

- There are facilities layer internal interfaces from the message services to the MCO_FAC to establish the message dataflow.

- The NF-SAP can be used for the dataflow between the MCO_FAC and singular or multiple Networking layers.

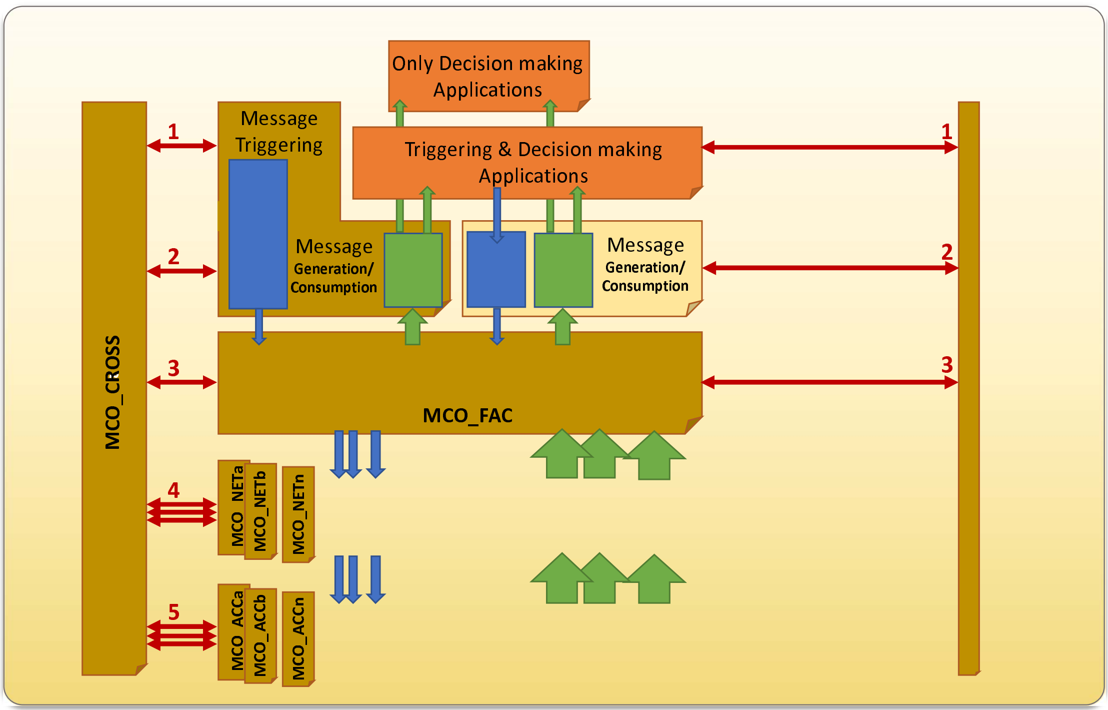


Figure 44: Proposed MCO architecture

Multiple MCO_NET and MCO_ACC may be needed, as illustrated in Figure 44.

10 Recommendations

10.1 Introduction

In clause 9 the MCO approaches proposed are described which leads to a number of recommendations to be considered when specifying the MCO functionalities and related aspects. In the following clauses the recommendations are illustrated.

10.2 Message exchange predictability

As shown in clause 5.5.4 message generation is initiated by applications or awareness services which trigger the message generation and transmission to be realized by message services. In Release 1, applications and awareness services were only triggering the transmissions of CAM, DENM, SPATEM, MAPEM and IVIM in a single channel (SCH0) where the usage of the channel was simply managed by a congestion control mechanism and the message priority levels which could easily lead to predictable robust C-ITS Release 1 system.
A Release 2 and beyond C-ITS and beyond system will have to deal with many more applications and awareness services than a Release 1 C-ITS system. It is expected to use multiple channels and possible different access technologies which makes it much more complex than a Release 1 system. As identified in clause 5.3, a C-ITS-S will be equiped with a given number of radio interfaces implemented which limits the channel use mechanisms as identified in clause 9.4. As a result, at least for Release (like for Release 1) the use of the channels should be application and awareness service specific to ensure the stable operation of all applications and awareness services.

It is therefore recommended that for each application or awareness service and their corresponding messages it is clearly specified how each application or awareness service makes use of the channels. This could include technology related parameters but where possible this should be avoided. It is recommended to define a number of MCO related application and awareness service principles to guide future applications and awareness service specification development. Different approaches are recommended for those based on the exchange of broadcast messages than those based on groupcast (or multicast or unicast) messages. This is the case because groupcast (or multicast or unicast) messages are only targeted to a concrete number of C-ITS-S interested in certain application or awareness service, and thus allow that the channel is dynamically selected based on their capabilities, requirements and the status of the channels. Differently, broadcast messages can be needed by any C-ITS-S within the coverage range of the transmitting C-ITS-S, which prevents the dynamic negotiation of the channel used by the interested C-ITS-S.

10.3 Multi-channel congestion control

Congestion control mechanisms were designed in Release 1 specifications to ensure a robust system operation by maintaining the channel load under control. To this aim, congestion control protocols dynamically adapt the channel load generated and transmitted by each C-ITS-S (i.e. by each application and awareness service).

In a multi-channel system, congestion control protocols are recommended to include the possibility to offload certain messages to other channel(s) if they do not fit into a given channel. Following clause 10.2, the behavior of applications and awareness services and their corresponding messages when offloading mechanisms are applied needs to be agreed. The utility of offloading possibilities depends on whether C-ITS-S can receive the offloaded messages if they are transmitted in another channel, which certainly depends on the number of radio interfaces they implement.
The implication of MCO on the DCC mechanisms (including DCC_ACC, DCC_NET, DCC_CROSS and DCC_FAC) as identified in ETSI TS 103 175 [i.118] needs to be considered and realized in a backward compatible manor.

10.4 Message priorities

In Release 1, given number of channel access priority levels were defined to differentiate the channel access rights of each message type. In a multi-channel system, it is recommended that priorities are also defined for each application or awareness service and their corresponding messages with regards to their rights to transmit a message in a given channel. Based on this priority level, when a channel is overloaded, congestion control mechanisms are recommended to restrict the transmission of messages with lower channel selection priority level in such channel by e.g. offloading them or internally dropping them. Channel selection priority levels need to be agreed among all users and implementers and can be equal to the channel access priorities or not, depending on the needed granularity.

10.5 MCO interference management

In the clauses 7 and 8 the different capability aspects and their analyses are provided. These clauses show that interference from second and futher adjacent channels is negligible but that from the first adjacent channel it is not. It is identified that some interference could take place but that would be manageable when in the adjacent channels the load of the channel is limited by setting lower CBR values. In clause 9 the adjacent channels have been assigned but the parameter and its settings are not yet defined. Further study should lead to identification the CBR value to use.

As identified in clauses 7 and 8, transmit power is not the way to manage the channels. It is recommended to set transmit power conditions according to the area of relevance for a given message to extend congestion control mechanisms.

10.6 Use of non-safety related channels for safety related message transmissions

As identified in clause 8 and clause 9.4.8.3 and analysed in clause F.1 under certain conditions the non-safety channels could be used for safety related C-ITS data exchange. In clause F.1 only one scenario based on ITS-G5 is investigated. It is recommended to realize further studies under what conditions the non-safety C-ITS channels in the 5 855 MHz to 5 875 MHz band could be used for safety related C-ITS message exchange. This could include critical safety scenarios and different technologies.

10.7 Channel assignment for SAS

As identified in clause 6.3.2 and clause 9.4.8.4 for a specific application, stakeholders could use the SAS service to inform interested parties about how to received information relevant for the specific application e.g. the channel, type of media and parameter settings. This can be decided by each stakeholder itself, additionally it is advised to identify a specific channel and possibly technical settings by which general SAEMs could be distributed for general purpose. It is recommended for a robust MCO operation to identify the SCH0 as the channel in which SAEMs supporting general safety applications are transmitted and SCH4 for all SAEMs supporting non-safety related applications.

Annex A: Multi-channel interference effects for ITS-G5

A.1 Overview

The main technical characteristics and operational principles of the ETSI ITS-G5 access layer are taken from the IEEE 802.11-2020 [i.108] specification. These characteristics are adapted to the European requirements (mainly spectrum requirements) in the ETSI EN 302 663 [i.22].

The MAC layer operation (mainly CSMA/CA access) and the related parameters are identical to the specification in IEEE 802.11-2020 [i.108] and have not been changed in the ETSI EN 302 663 [i.22] access layer profile standard.

The main parameters which have been adapted are:

- sensitivity;
- TX mask or adjacent channel leakage ratio; and
- selectivity including blocking rejection.

A.2 Sensitivity

In Table A.2-1 the static receiver sensitivity of a TS-G5 receiver is depicted as specified in ETSI EN 302 663 [i.22] and IEEE 802.11-2020 [i.108]. The dynamic sensitivity is 3 dB below this static sensitivity. In ETSI EN 302 663 [i.22] only a sensitivity value for the QPSK rate $R = ½$ is defined for the dynamic case in order to reduce the overall test effort. Real implementation will reach better values. In the context of the present document, we will use the values given in Table A.2-1 will be used. The values in the IEEE 802.11-2020 [i.108] are less stringent by 6 dB and no dynamic channel performance criterions are included.

Table A.2-1: Static receiver sensitivity in ETSI EN 302 663 [i.22] and IEEE 802.11-2020 [i.108]

Transfer rate (Mbit/s)	Modulation	Coding rate	Minimum sensitivity for 10 MHz channel spacing (dBm) [i.22]	Minimum sensitivity for 10 MHz channel spacing (dBm) [i.108]
3	BPSK	1/2	-91	-85
4,5	BPSK	3/4	-90	-84
6	QPSK	1/2	-88	-82
9	QPSK	3/4	-86	-80
12	16-QAM	1/2	-83	-77
18	16-QAM	3/4	-79	-73
24	64-QAM	2/3	-75	-69
27	64-QAM	3/4	-74	-68

A.3 Adjacent channel rejection

In Table A.3-1 the values for the adjacent channel rejection are given as defined in ETSI EN 302 663 [i.22]. These values correspond to the enhanced rejection values as defined in IEEE 802.11-2020 [i.108].

Table A.3-1: Limits for receiver adjacent channel rejection and alternate adjacent channel rejection [i.22]

Transfer rate (Mbit/s)	Modulation	Coding rate	Adjacent channel rejection (dB)	Alternate adjacent channel rejection (dB)
3	BPSK	1/2	28	42
4,5	BPSK	3/4	27	41
6	QPSK	1/2	25	39
9	QPSK	3/4	23	37
12	16-QAM	1/2	20	34
18	16-QAM	3/4	16	30
24	64-QAM	2/3	12	26
27	64-QAM	3/4	11	25

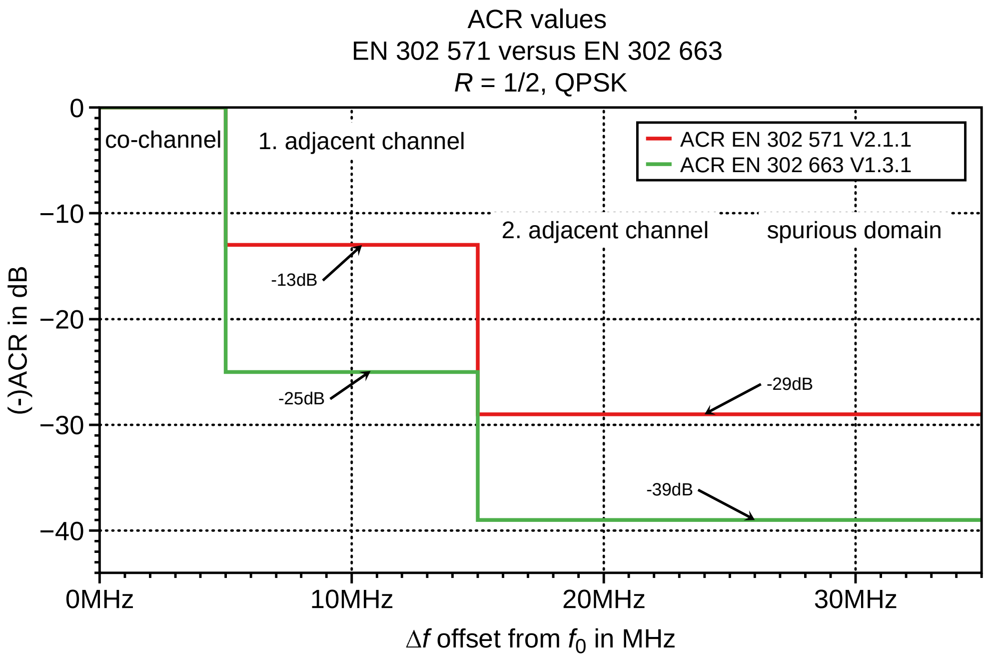


Figure A.3-1: Adjacent channel rejection ETSI EN 302 571 [i.19] and ETSI EN 302 663 [i.22], QPSK with R = ½

In Figure A.3-1 it can be seen that the enhanced selectivity figure in ETSI EN 302 663 [i.22] are significantly more stringent than the one originally specified in the harmonised standard ETSI EN 302 571 [i.19]. The ACR is represented as negative value (-ACR) to make the attenuation of the interference visible. For the values in the spurious domain the same values as the ones in the two adjacent channel has been assumed since no values are specified in the standards. In real implementation an additional rejection can be assumed here.

The ACR is a modulation and coding scheme dependent parameter. For further investigations and the direct comparison with the adjacent channel leakage effect the Adjacent Channel Selectivity (ACS) is a better value to be taken into account. From the ACR value given in the ETSI EN 302 663 [i.22] the modulation and coding scheme independent ACS can be calculated as follows:

$$ACS = ACR + 3 \text{ dB} + SNR$$

Where SNR represents the required SNR value for a given modulation (for QPSK with R = ½ we assume 6 dB). The 3 dB are the margin taken in ETSI EN 302 663 [i.22] for the ACR measurement procedure.

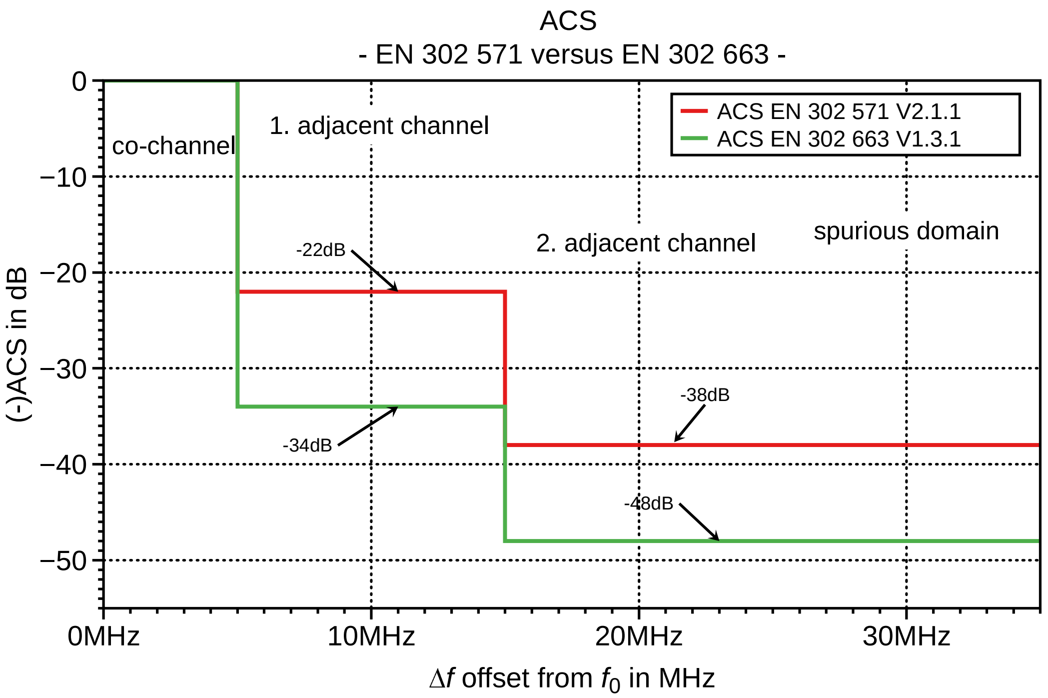


Figure A.3-2: Adjacent channel selectivity ACS based on ETSI EN 302 571 [i.19] and ETSI EN 302 663 [i.22], QPSK with R=½

In Figure A.3-2 the resulting ACS values are depicted for ETSI EN 302 571 [i.19] and ETSI EN 302 663 [i.22]. The ACS values are depicted as attenuation value (-ACS) and thus they are negative.

The minimum ACS value for the first adjacent channel is 34 dB. Thus, for a 33 dBm interfering transmitter in the adjacent channel the victim receiver will experience an interference level of -1 dBm in 10 MHz (plus path loss and other effects) from the selectivity effects of the RX. For a 23 dBm TX level this value is -11 dBm. These power levels are depicted in Figure A.3-3 for different interferer TX power levels. The values in the spurious domain are not taken into account here.

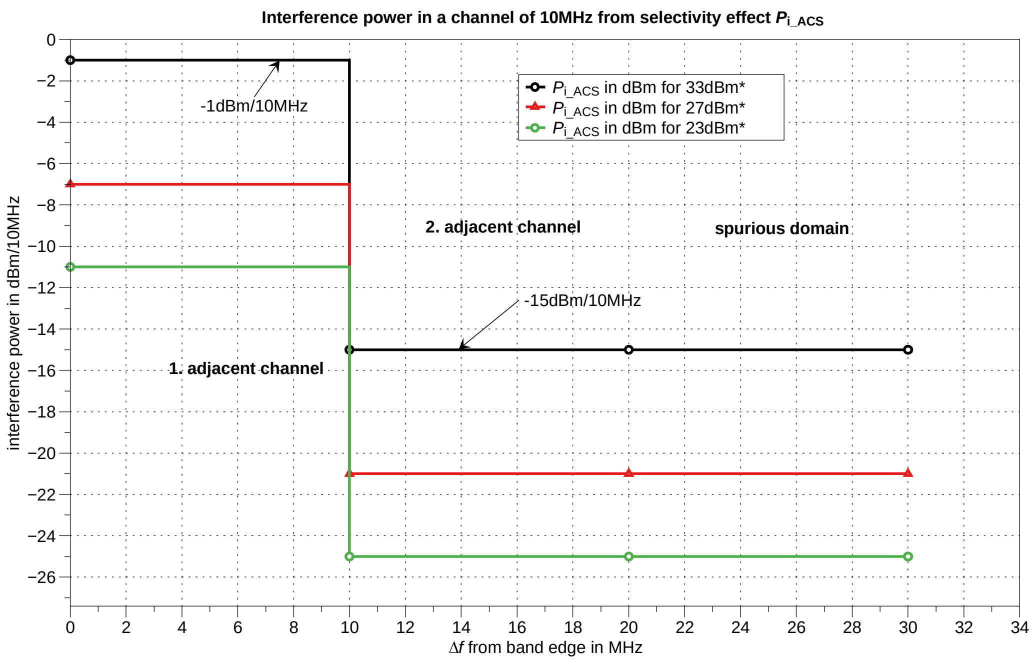


Figure A.3-3: Adjacent channel selectivity ACS

A.4 TX spectrum mask

The assumed TX spectrum mask is given in Table A.4-1 based on the spectrum mask in ETSI EN 302 571 [i.19]. It specifies a spectrum mask in absolute values and a measurement bandwidth of 100 kHz. All C-ITS devices operating in the band 5 855 MHz to 5 925 MHz have to fulfil this mask independent of the transmit power. In real operation it can be assumed that a device with less than the maximum allowed 33 dBm e.i.r.p. TX power will have a reduced adjacent channel power level. TX power will have a reduced adjacent channel power level. The adjacent channel power level reduction will not be fully proportional to the TX power reduction.

Table A.4-1: Out-of-band emission limits in draft ETSI EN 302 571 [i.19]

Frequency offset to carrier frequency (MHz)	Emission limits (dBm e.i.r.p.)	Measurement bandwidth
±5.0	-13	100 kHz
±5.5	-19	100 kHz
±10	-27	100 kHz
±15	-37	100 kHz
±25	-40	100 kHz

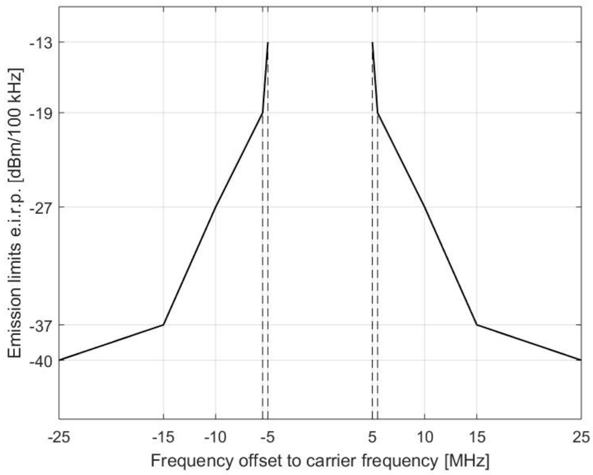


Figure A.4-1: Transmitter spectrum mask draft ETSI EN 302 571 [i.19]

Based on the figures in Figure A.4-2 the interfering power in the adjacent channel resulting from the Adjacent Channel Leakage (ACL) out of band emission for a 33 dBm interferer TX level will be around -3,6 dBm in the 10 MHz first adjacent channel and -18,4 dBm in the second adjacent channel. These values are the integration over 10 MHz channel bandwidth in the log domain using the values in Table A.4-1.

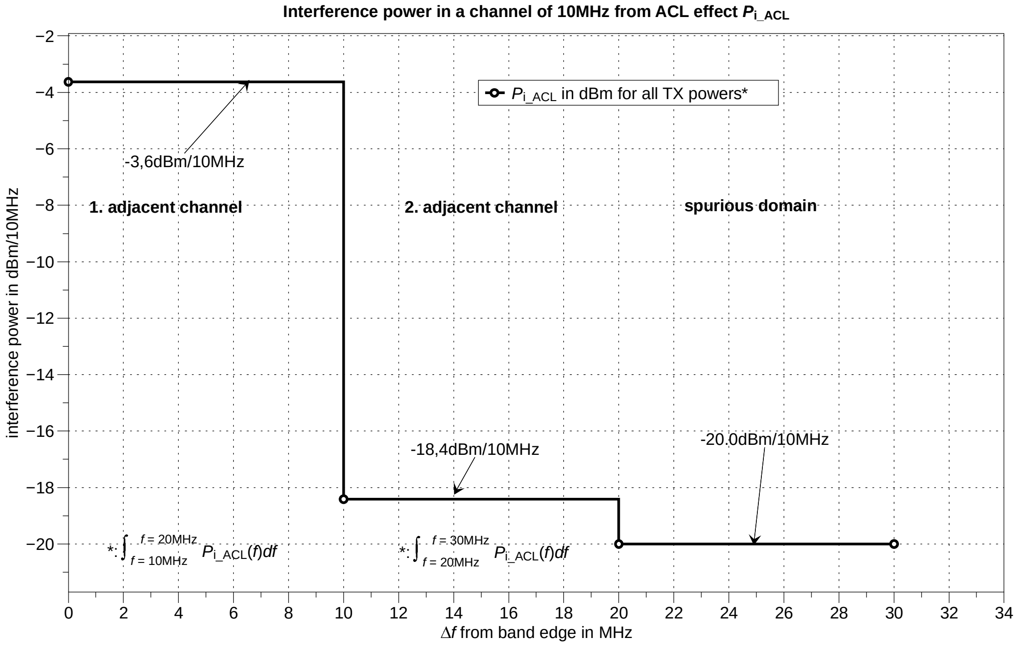


Figure A.4-2: ACL P_{i_ACL} based on draft ETSI EN 302 571 [i.19]

A.5 Combined unwanted emission and selectivity effects

The effective transmitted interference power of an interfering transmitter is depicted in Figure A.5-1 to Figure A.5-3 for different TX power levels from 23 dBm to 33 dBm.

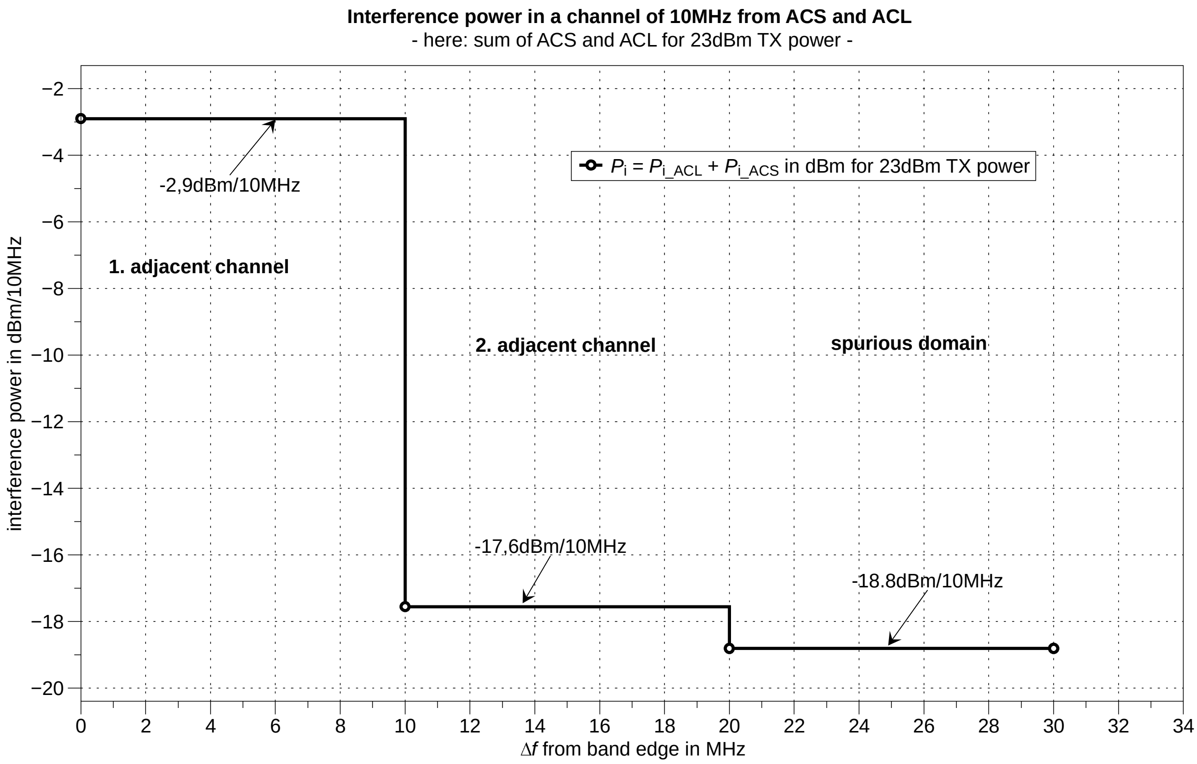


Figure A.5-1: Example for ITS-G5: Effective interference power at the interfering TX $P_{TX\_int\_eff}$ as combination of ACLR and ACS effect for 23 dBm TX power

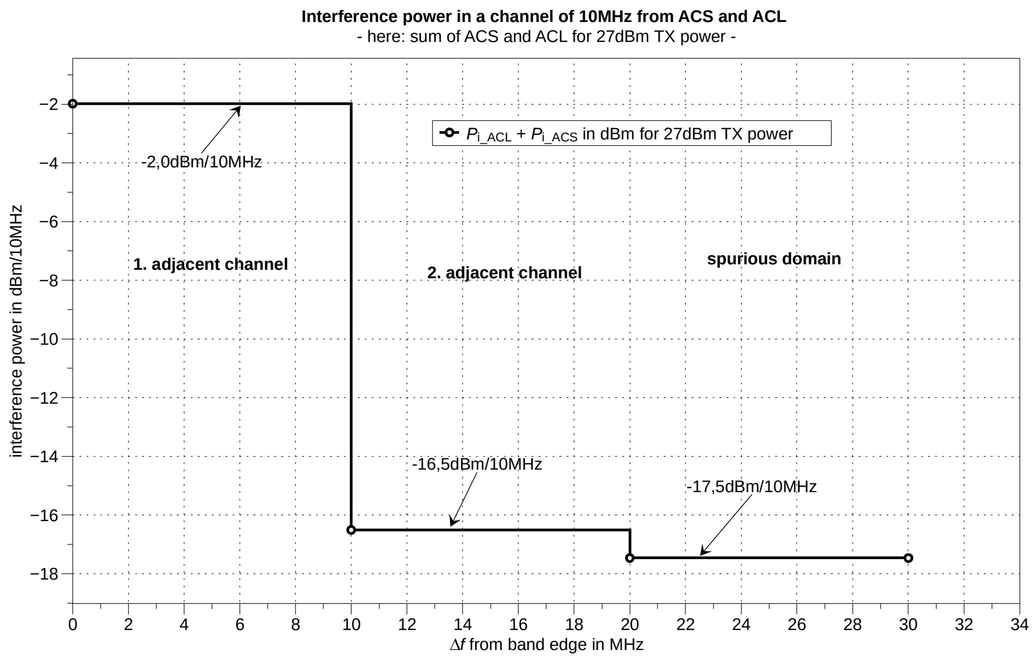


Figure A.5-2: Example for ITS-G5: Effective interference power at the interfering TX $P_{TX\_int\_eff}$ as combination of ACLR and ACS effect for 27 dBm TX power

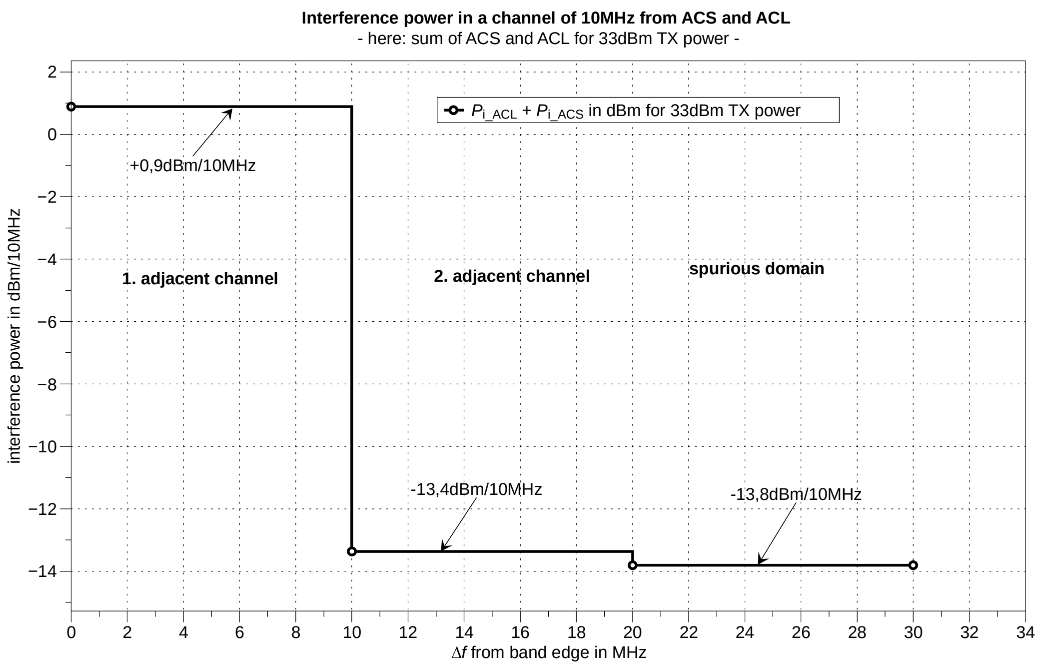


Figure A.5-3: Example for ITS-G5: Effective interference power at the interfering TX $P_{TX\_int\_eff}$ as combination of ACLR and ACS effect for 33 dBm TX power

A.6 Conclusion ITS-G5

Two parameters in the set of specifications outlined above will mainly govern the physical layer MCO behaviour of an ITS system:

- Selectivity (Adjacent channel selectivity).
- TX spectrum mask (Adjacent channel leakage or out off band emission).

If the raw figures are considered, it can be concluded that the main limiting factor for the MCO specification for a system using 33 dBm TX power will be the ACS effect. In this case the interference created by the transmitter in the adjacent channel is 2,6 dB lower than the effect resulting from the selectivity, see Figure A.6-1.

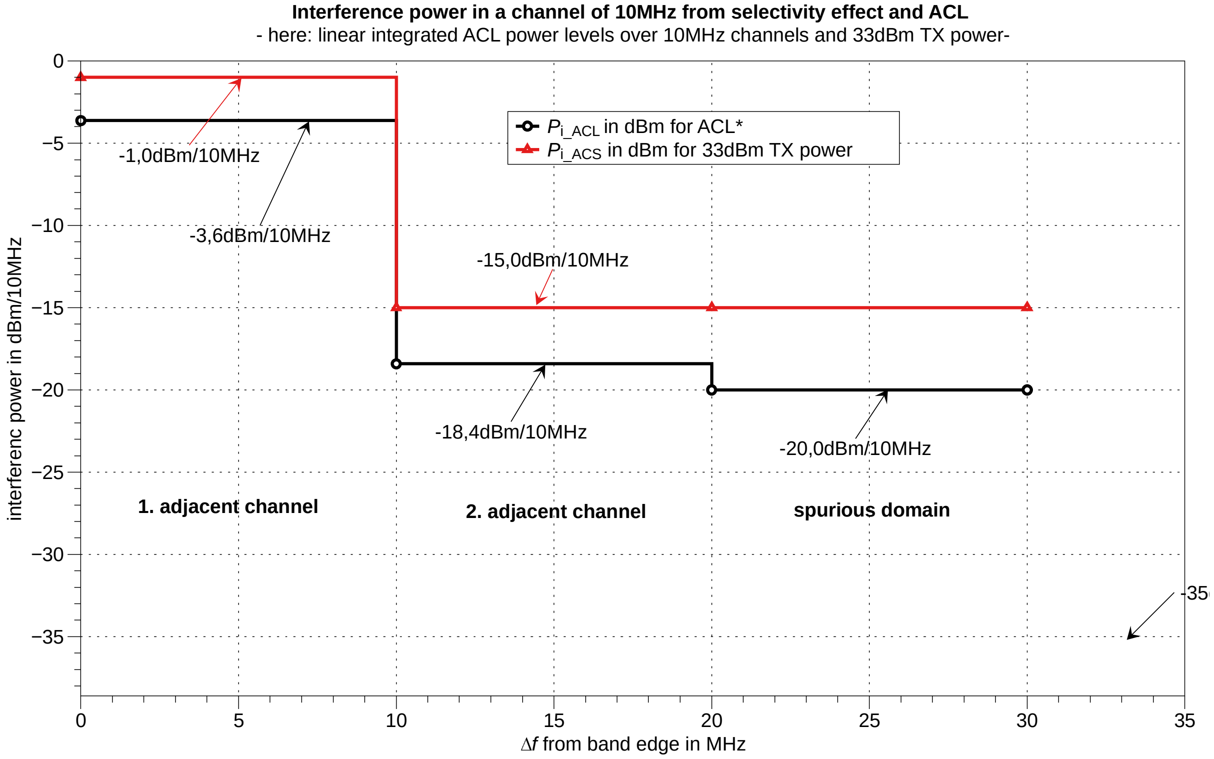


Figure A.6-1: Example for ITS-G5: Comparison of ACS and ACL effects for 33 dBm TX power

For lower TX power levels, the main interference factor will be the ACL effect, see Figure A.6-2 and Figure A.6-3. This is due to the fact that the limits for the TX mask are given in absolute values whereas the selectivity limits are given in relative values relative to the interference level in the adjacent channel. Thus, a decreased TX power of the interferer in the adjacent channel will almost linearly decrease the interference effect from the selectivity effect into the victim RX. In the worst-case, the unwanted emission level given by the ACL of the same interfering transmitter will not decrease.

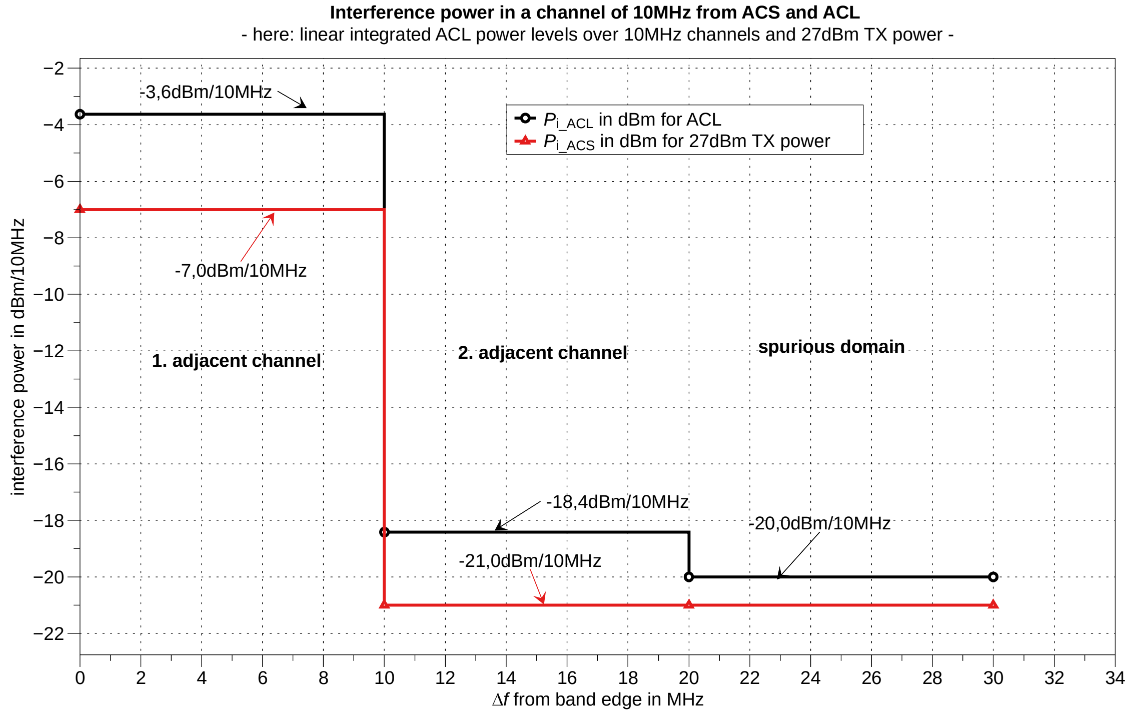


Figure A.6-2: Example for ITS-G5: Comparison of ACS and ACL effects for 27 dBm TX power

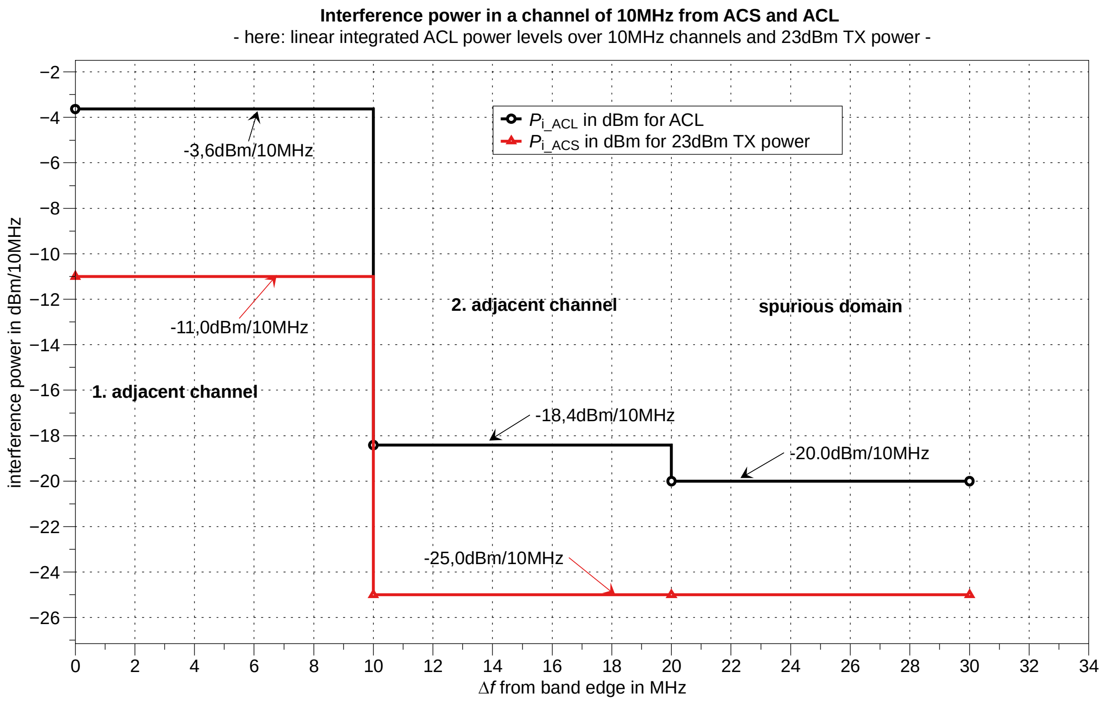


Figure A.6-3: Example for ITS-G5: Comparison of ACS and ACL effects for 23 dBm TX power

The effective interference power levels at the interfering TX for different TX powers are given in Table A.6-1 for the ITS-G5 specifications.

Table A.6-1: Example for ITS-G5: Effective interference power at the interfering TX as combination of ACL and ACS effect

	Effective interference power $P_{i\_ACS} + P_{i\_ACL}$ at the interfering TX as combination of ACL and ACS effect in dBm/10 MHz		
Transmit power (dBm)	**Δf = [0 10] MHz**	**Δf = [10 20] MHz**	**Δf = [20 ∞] MHz**
33	+0,9	−13,4	−13,8
27	−2,0	−16,5	−17,5
23	−2,9	−17,6	−18,8

Annex B: Multi-channel interference effects for LTE-V2X

B.1 Overview

The main technical characteristics and operational principles of the ETSI LTE-V2X access layer are taken from 3GPP technical specifications for LTE-V2X PC5. These characteristics are adapted to the European requirements (mainly spectrum requirements) in the ETSI EN 303 613 [i.23].

The MAC layer operation (based on semi persistent scheduling) and the related parameters are identical to the 3GPP tec specification in ETSI TS 136 213 [i.99] and the ETSI EN 303 613 [i.23] access layer profile standard described in Annex B specific parameters.

The RF requirements applicable to LTE-V2X are defined in ETSI TS 136 101 [i.117].

B.2 Sensitivity

The minimum reference sensitivity requirements for LTE-V2X are given by clause 7.3.1G in ETSI TS 136 101 [i.117]. Table 7.3.1G-1 in ETSI TS 136 101 [i.117] defines for a 10MHz channel bandwidth the LTE-V2X reference sensitivity power level $P_{REFSENS\_V2X} = -90{,}4$ dBm, the power level at which the throughput should be ≥ 95 % of the maximum throughput of the reference measurement channel. The fixed reference measurement channel, specified in clause A.8.2 of ETSI TS 136 101 [i.117], is defined according to Table B.2-1.

Table B.2-1: Fixed reference measurement channel for V2X receiver requirements from ETSI TS 136 101 [i.117]

Parameter	Unit	Value
Channel bandwidth	MHz	10
Allocated resource blocks		48
Subcarriers per resource block		12
Packets per period		1
Modulation		QPSK
Target Coding Rate		1/3
Transport Block Size		3 496
Transport block CRC	Bits	24
Number of Code Blocks per Sub-Frame		1
Maximum number of HARQ transmissions		1
Binary Channel Bits per subframe	Bits	11 520
Max. Throughput averaged over 1 period of 100 ms	kbps	34,96
UE Category		≥ 1
NOTE 1: 2 RBs allocated to SA transmission and 4 symbols allocated to RS. NOTE 2: Throughput (in kbps) will depend on SA period configuration. NOTE 3: If more than one Code Block is present, an additional CRC sequence of L = 24 Bits is attached to each Code Block (otherwise L = 0 Bit).		

These requirements are the minimum requirements for an LTE-V2X receiver to pass the 3GPP defined test cases. Real implementation will reach better values. The test is only defined for one modulation and coding scheme with QPSK and coding rate 1/3, cf. also Table B.2-1. This can be explained by the fact that the intention of the test is to ensure that the receive operates well close to the noise floor. The demodulation performance for higher modulation and higher coding rates is tested via demodulation performance requirements for the individual physical channels in clause 14 of ETSI TS 136 101 [i.117]. The fixed reference measurement channel in Table B.2-1. is used for all LTE-V2X receiver characteristics tests, including the adjacent channel selectivity and in-band blocking.

B.3 Adjacent channel rejection

To define the adjacent channel rejection, 3GPP relies on the Adjacent Channel Selectivity (ACS) definition. The Adjacent Channel Selectivity is defined in clause 7.5 of ETSI TS 136 101 [i.117] as follows:

> *Adjacent Channel Selectivity (ACS) is a measure of a receiver's ability to receive a E-UTRA signal at its assigned channel frequency in the presence of an adjacent channel signal at a given frequency offset from the centre frequency of the assigned channel. ACS is the ratio of the receive filter attenuation on the assigned channel frequency to the receive filter attenuation on the adjacent channel(s).*

For LTE-V2X, clause 7.5.1G in ETSI TS 136 101 [i.117] defines the minimum ACS requirements: *"The LTE-V2X receiver shall fulfil the minimum requirement, ACS = 33,0 dB for a channel bandwidth of 10 MHz, for all values of an adjacent channel interferer up to -22 dBm"*. However, it is not possible to directly measure the ACS, instead the lower and upper range of test parameters are chosen for the two test cases in Table B.3-1 and Table B.3-2 where the throughput has to be ≥ 95 % of the maximum throughput of the reference measurement channels as specified in Table B.2-1. The Power in Transmission Bandwidth Configuration corresponds to the power level of the wanted receive signal, while $P_{Interferer}$ defines the power level of the interferer in the channel with bandwidth $BW_{Interferer}$ and carrier frequency offset $F_{Interferer}$.

Table B.3-1: Test parameters for adjacent channel selectivity for LTE-V2X, Case 1 from ETSI TS 136 101 [i.117]

Rx Parameter	Units	Channel bandwidth
		10 MHz
Power in Transmission Bandwidth Configuration	dBm	-76,4
$P_{Interferer}$	dBm	-44,9
$BW_{Interferer}$	MHz	10
$F_{Interferer}$ (offset)	MHz	10 + 0,0125 / -10 - 0,0125
NOTE: The interferer is QPSK modulated PUSCH containing data and reference symbols. Normal cyclic prefix is used. The data content needs to be uncorrelated to the wanted signal and modulated according to clause 5 of ETSI TS 136 211 [i.101].		

Table B.3-2: Test parameters for adjacent channel selectivity for LTE-V2X, Case 2 from ETSI TS 136 101 [i.117]

Rx Parameter	Units	Channel bandwidth
		10 MHz
Power in Transmission Bandwidth Configuration	dBm	-53,5
$P_{Interferer}$	dBm	-22
$BW_{Interferer}$	MHz	10
$F_{Interferer}$ (offset)	MHz	10 + 0,0125 / -10 - 0,0125
NOTE: The interferer is QPSK modulated PUSCH containing data and reference symbols. Normal cyclic prefix is used. The data content needs to be uncorrelated to the wanted signal and modulated according to clause 5 of ETSI TS 136 211 [i.101].		

For both case 1 and case 2 the equivalent ACR is 31,5 dB. As indicated above, the idea is to define two test cases, where test case 1 operates at the highest interferer power and test case 2 at a low interferer power where the power in the transmission bandwidth is still 14 dB above the reference sensitivity level.

The adjacent channel selectivity described in clause 7.5.1G in ETSI TS 136 101 [i.117] is only applicable to the "first" adjacent channel, i.e. with a centre frequency offset of ±10 MHz from the carrier frequency. For the "second" and "third" adjacent channel, i.e. with a centre frequency offset of ±20 MHz and ±30 MHz, respectively, the in-band blocking requirement is applicable.

According to ETSI TS 136 101 [i.117] clause 7.6.1.1G, in-band blocking is defined for an unwanted interfering signal falling into the UE receive band or into the first 15 MHz below or above the UE receive band at which the relative throughput will have to meet or exceed the minimum requirement for the specified measurement channels. This requirement is comparable to the alternate adjacent channel rejection for ITS-G5. The LTE-V2X UE throughput needs to be ≥ 95 % of the maximum throughput of the reference measurement channels as specified in Table B.2-1 with parameters defined in Table B.3-3 and Table B.3-4.

Table B.3-3: In band blocking parameters for LTE-V2X from ETSI TS 136 101 [i.117]

Rx parameter	Units	Channel bandwidth
		10 MHz
Power in Transmission Bandwidth Configuration	dBm	-84,4
$BW_{Interferer}$	MHz	10
$F_{Ioffset, case 1}$	MHz	15 + 0,0025
$F_{Ioffset, case 2}$	MHz	25 + 0,0075
NOTE: The interferer is QPSK modulated PUSCH containing data and reference symbols. Normal cyclic prefix is used. The data content needs to be uncorrelated to the wanted signal and modulated according to clause 5 of ETSI TS 136 211 [i.101]		

Table B.3-4: In band blocking additional parameters from ETSI TS 136 101 [i.117]

E-UTRA V2X band	Parameter	Unit	Case 1	Case 2
	$P_{Interferer}$	dBm	-44	-44
	$F_{Interferer}$ (offset)	MHz	= -5 - $F_{Ioffset,case 1}$ & = +5 + $F_{Ioffset,case 1}$	≤ -5 - $F_{Ioffset,case 2}$ & ≥ +5 + $F_{Ioffset,case 2}$
47	$F_{Interferer}$	MHz	(NOTE 2)	F_{DL_low} -30 to F_{DL_high} + 30
NOTE 1: For certain bands, the unwanted modulated interfering signal may not fall inside the UE receive band, but within the first 15 MHz below or above the UE receive band. NOTE 2: For each carrier frequency the requirement is valid for two frequencies: a. the carrier frequency -5 - $F_{Ioffset, case 1}$;and b. the carrier frequency +5 + $F_{Ioffset, case 1}$. NOTE 3: $F_{Interferer}$ range values for unwanted modulated interfering signal are interferer centre frequencies.				

For this scenario, an Adjacent Channel Rejection (ACR) of 40,4 dB is required according to the test description. The power in the transmission bandwidth is 6 dB above the reference sensitivity level. The test case 1 tests the in-band blocking at an interferer centre frequency of exactly 20,0025 MHz. The test case 2 is used to test the remaining adjacent channels that are up to 30 MHz below the lower band edge (F_{DL_low}) and 30 MHz above the upper band edge (F_{DL_high}). For the E-UTRA V2X band 47 the band edges are F_{DL_low} = 5 855 MHz and F_{DL_high} = 5 925 MHz.

ETSI TS 136 101 [i.117] also defines out-of-band band blocking requirements for an unwanted Continuous Wave (CW) interfering signal falling more than 15 MHz below or above the UE receive band. Those requirements are not applicable to the MCO case since the MCO interference will only originate from within the E-UTRA V2X band 47.

The equivalent ACS for the in-band blocking can be calculated by:

$$\mathrm{ACS} = \mathrm{ACR} + \mathrm{P}_{\mathrm{REFSENS}_{\mathrm{V2X}}} - \mathrm{NoiseFigure} - \mathrm{ThermalNoise} = 42{,}0\ \mathrm{dB}$$

using ACR = 40,4 dB, $\mathrm{P}_{\mathrm{REFSENS\_V2X}} = -90{,}4$ dBm, a noise figure of 12 dB as assumed by the 3GPP standard, and the thermal noise for 10 MHz equal to -104 dBm.

The minimum adjacent channel rejection requirements of LTE-V2X are summarized using the ACS metric in Figure B.3-1.

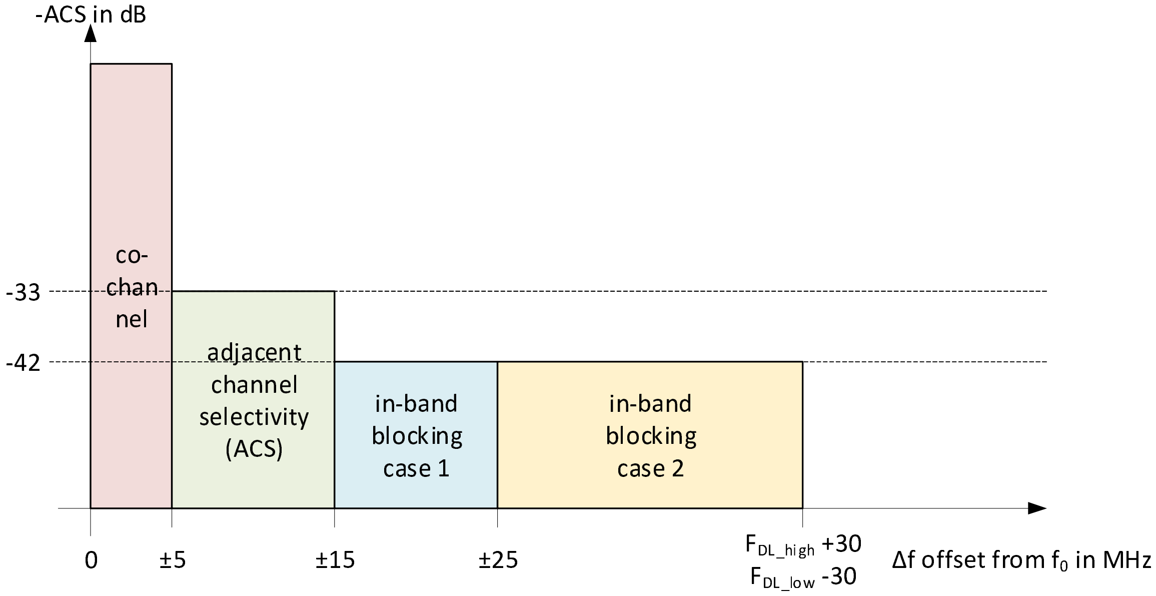


Figure B.3-1: ACS for LTE-V2X

It has to be noted that the in-band blocking ACS values are defined for the second adjacent channel. In real systems, the ACS value will increase with the distance to the carrier. Therefore, even though 3GPP does not define any tighter requirements for the "third" adjacent channel, it is to be assumed that the ACS for this channel will be better than the in band blocking requirement.

The limits given by the 3GPP specification are significantly more stringent than the ones specified in the harmonised standard ETSI EN 302 571 [i.19].

Assuming an interferer with interference power levels 33 dBm, 27 dBm and 23 dBm, respectively, the interference power experienced due to adjacent channel selectivity is depicted in Figure B.3-2.

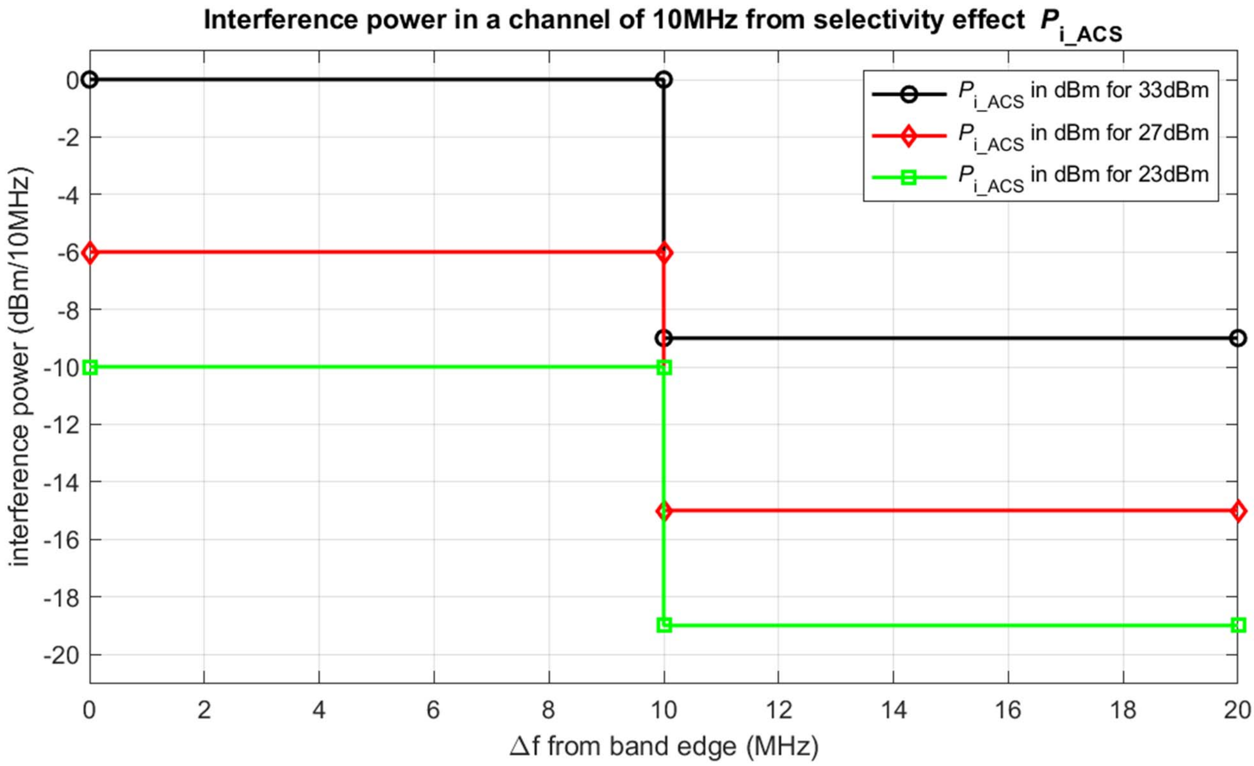


Figure B.3-2: Interference power in channel of 10 MHz from selectivity effect depending on received power level

B.4 TX spectrum mask

The transmit spectrum mask is identical for LTE-V2X and ITS-G5. Therefore, the transmitter spectrum mask and the Adjacent Channel Leakage (ACL)/out of band emission described in clause A.4 for ITS-G5 is also valid for LTE-V2X.

B.5 Combined unwanted emission and selectivity effects

The effective transmitted interference power of an interfering transmitter is depicted for LTE-V2X in Figure B.5-1 for a TX power of 33 dBm, 27 dBm and 23 dBm, respectively.

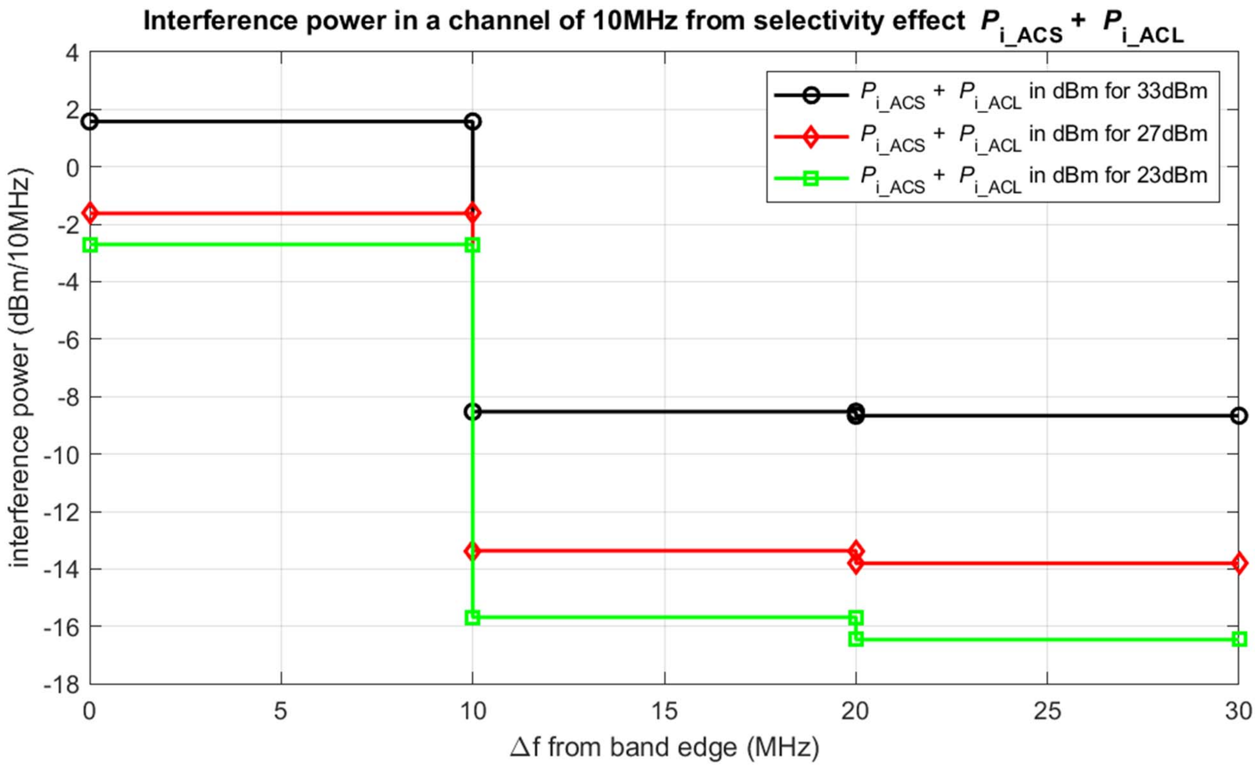


Figure B.5-1: Example for LTE-V2X: Effective interference power at the interfering TX as combination of ACL and ACS effect

Table B.5-1 summarizes the interference power values for the first adjacent channel (Δf = [0 10] MHz), second adjacent channel (Δf = [10 20] MHz), and the spurious domain (Δf = [20 ∞] MHz), respectively, depending on the transmit power.

Table B.5-1: Example for LTE-V2X: Effective interference power at the interfering TX as combination of ACL and ACS effect

	Effective interference power $P_{i\_ACS} + P_{i\_ACL}$ at the interfering TX as combination of ACL and ACS effect in dBm/10 MHz		
Transmit power (dBm)	**Δf = [0 10] MHz**	**Δf = [10 20] MHz**	**Δf = [20 ∞] MHz**
33	1,6	−8,5	−8,7
27	−1,6	−13,4	−13,8
23	−2,7	−15,7	−16,5

B.6 Conclusions LTE-V2X

Two parameters in the set of specifications outlined above will mainly govern the physical layer MCO behaviour of an ITS system:

- Selectivity (Adjacent channel selectivity).
- TX spectrum mask (Adjacent channel leakage or out off band emission).

If the raw figure is considered, it can be concluded that the main limiting factor for the MCO specification for a system using 33 dBm TX power will be the ACS effect. In this case the interference created by the transmitter in the adjacent channel is 4 dB lower than the effect resulting from the selectivity, see Figure B.6-1.

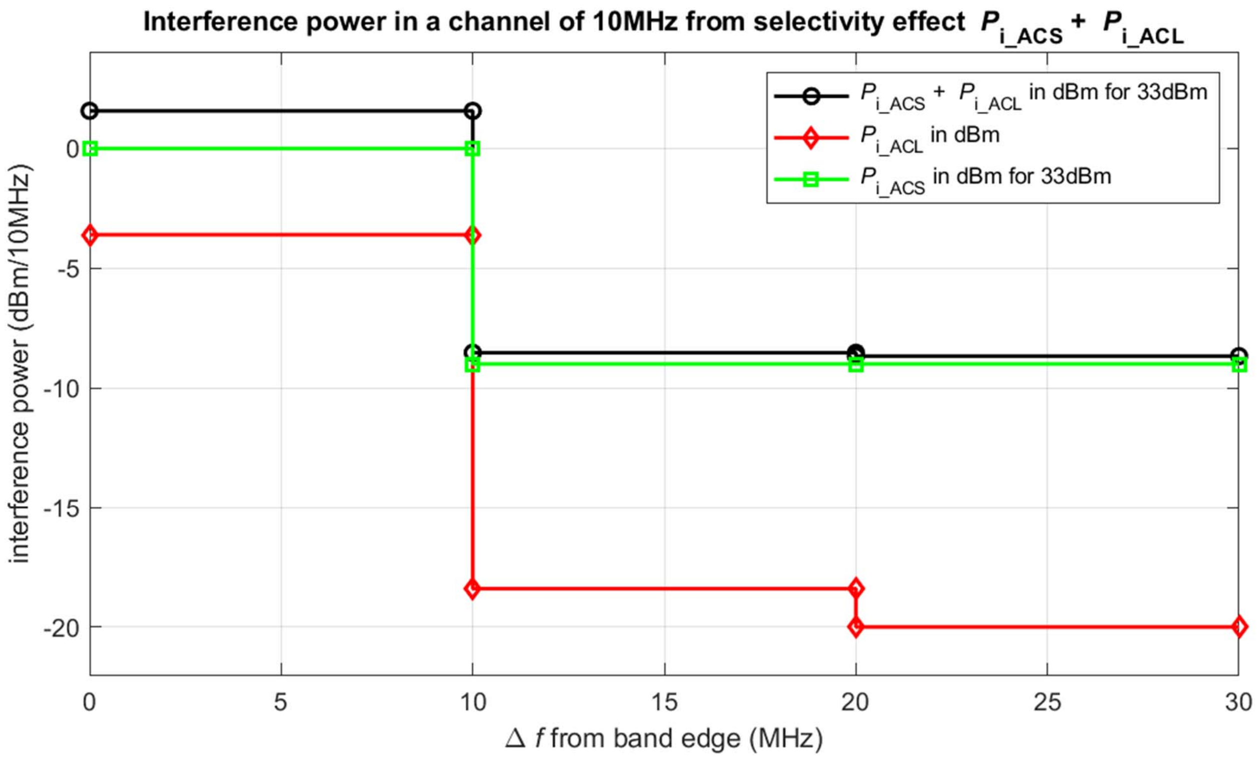


Figure B.6-1: Aggregated interference power for 33 dBm

For lower TX power levels, the main interference factor will be the ACL effect, see Figure B.6-2. This is because the limits for the TX mask are given in absolute values whereas the selectivity limits are given in relative values relative to the interference level in the adjacent channel. Thus, a decreased TX power of the interferer in the adjacent channel will almost linearly decrease the interference effect from the selectivity effect into the victim RX. In the worst-case, the unwanted emission level given by the ACL of the same interfering transmitter will not decrease.

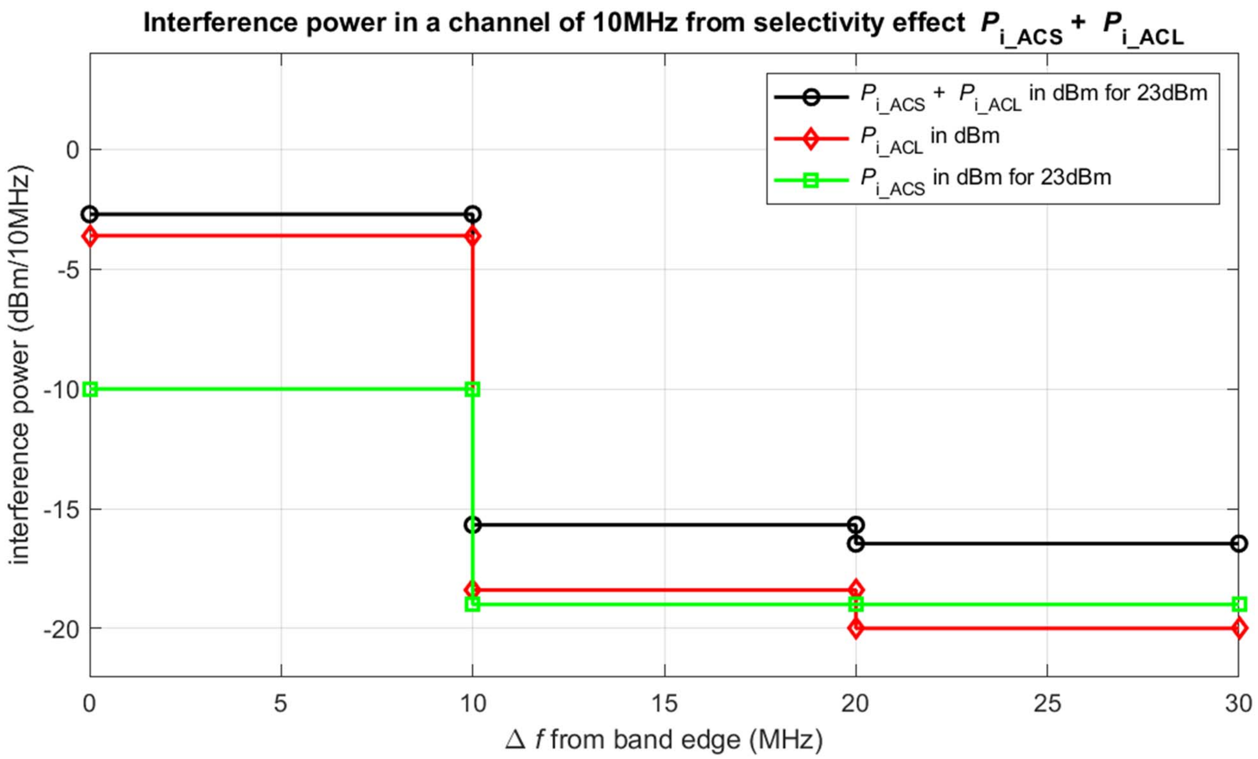


Figure B.6-2: Aggregated interference power for 23 dBm

Overall, we can conclude that the effects and values are very similar to the results obtained for ITS-G5 in clause A.6.

Annex C: MCO solutions and algorithms

C.1 ETSI TS 102 724

ETSI TS 102 724 [i.85] defines the channel usage in the ITS G5A and ITS G5B bands for multichannel operation. It includes both control and service channels, different application types (e.g. traffic safety and efficiency), defines transmit and receive policies, channel selection and configuration. It introduces per-traffic-stream and per-channel rate control. To do so, it defines a Channel-Configuration entity at the Access layer. The usage of the ITS-G5 channels is under control of the DCC and makes use of DCC profiles (DP1 to DP32). The Control Channel (CCH) is basically dedicated to cooperative road safety and is the default channel for the transmission of DP1 and DP2 messages. The transmissions of messages using higher DPs on the CCH are allowed in the DCC state "RELAXED". The Service Channel 1 (SCH1) is the default channel for announcing and offering ITS services for safety & road efficiency under the DCC state ACTIVE and RESTRICTIVE of the CCH. The Service Channel 2 (SCH2) is the second service channel on ITS G5A and is used as an alternate channel for traffic safety related services.

C.2 CARHet

C.2.1 Introduction

In [i.28], the authors propose CARHet, a multi-link and multi-RAT V2V communications solution that exploits multiple channels in a decentralized way. The proposed solution is technology and application agnostic and takes into account the application requirements and the communication context condition. While CARHet was evaluated in [i.28] considering different radio access technologies, the same concept could be applied to scenarios where all vehicles implement the same radio access technology but have multiple radio interfaces. The following clauses describe CARHet's channel access and usage strategies using the generic term "radio interface" and considering that each radio interface could implement the same or different radio access technology.

C.2.2 Channel access strategy

CARHet assumes that all vehicles are equipped with as many radio interfaces as radio channels available. They consider that vehicles are able to simultaneously use different radio interfaces for data transmission and/or reception. Moreover, each radio interface is tuned (fixed) to a specific channel in a specific frequency band. The selection of a radio interface is therefore equivalent to the selection of a channel. The authors also assume that a vehicle can transmit data using one radio interface and simultaneously receive information through all its radio interfaces.

CARHet was applied in [i.28] assuming that N radio interfaces are implemented, each of them tuned (fixed) to one of the M radio channels. However, CARHet could be evolved to adapt to scenarios where all vehicles do not implement as many radio interfaces as radio channels, i.e. $N<M$ for some vehicles, following the strategy described below.

C.2.3 Channel usage strategy

Each vehicle dynamically selects the radio interface that it will use to transmit all its messages. Since each radio interface is associated to a specific channel, the selection of the radio interface is equivalent to the selection of the radio channel to be used for data transmission. To select the radio interface (and channel), CARHet first filters out the radio interfaces whose capabilities do not support the application requirements (e.g. in terms of communications range). CARHet then selects the radio interface that minimizes the maximum channel load experienced by the neighbouring vehicles. To this aim, vehicles periodically measure and exchange the channel load they sense on all available channels. Vehicles are assumed to be capable to receive information on all channels and this channel selection strategy increases the amount of information that can be exchanged in the vehicular network due to a decrease in the interferences and packet loses due to collisions. CARHet also defines additional mechanisms to avoid unnecessary oscillations on the selected channel and radio access technology due to minor variations in the context conditions.

In scenarios where all vehicles do not implement as many radio interfaces as radio channels, vehicles could inform each other if they are not able to transmit/receive in a given channel, so that nearby vehicles stop using it. This could be done in the process used to exchange channel load information (e.g. indicating that a given channel is overloaded, so that other vehicles avoid using it).

CARHet has been shown to be capable to adequately distribute the load among different channels and ensure high and homogenous QoS levels across the network with a low computational and communication cost [i.28].

C.3 LTE-V2X RB allocation

C.3.1 Introduction

The LTE-V2X uses Single-Carrier Frequency-Division Multiple Access (SC-FDMA) and supports both 10- and 20 MHz channels as defined in ETSI TS 136 201 [i.112]. Each channel is divided into Resource Blocks (RBs), subchannels, and subframes as defined in ETSI TS 136 213 [i.99]. Each subframe has a duration of 1 ms and each RB consists of 12 subcarriers of 15 kHz (180 kHz wide in frequency). Subcarriers have 14 symbols in each subframe where 4 of these symbols are dedicated to the transmission of Demodulation Reference Signals (DMRSs) to address the doppler effect at high speed. In LTE-V2X, a subchannel is also a group of the RBs in the same subframe. Each subchannel consists of 10 RBs, and the number of subchannels in the corresponding resource pool can be flexibly determined to support the required bandwidth, e.g. a value of 5 for 10 MHz channels and a value of 10 for 20 MHz channels.

C.3.2 Channel access

There are two methods of channel access in LTE-V2X: Semi Persistent Scheduling (SPS), and One-Shot Transmission.

In LTE-V2X mode 4, a transmitter uses sensing-based Semi Persistence Scheduling (SPS) algorithm to reserve the channel and transmit the data. In this scheme, the transmitter senses the channel for one second of Sensing Window and reserves the selected subchannels for a number of R consecutive transmissions, where the reselection counter R is set randomly between five and fifteen.

To select a sub-channel, the transmitter makes a list, L1, of Candidate Subframe Resources (CSRs) in the selection window. The list L1 includes all the CSRs in the selection window except the ones that will be utilized. A CSR is recognized as utilized via a received SCI and average measured Reference Signal Received Power (RSRP) > Th_{SPS} over the RBs, where Th_{SPS} depends on the priority of the packet. Moreover, due to the half-duplex transmission mode, the transmitter should exclude all the CSRs of subframe F in the selection window if itself was transmitting during any previous subframe F-100 × j ($j \in N, 1 \leq j \leq 10$). After excluding the utilized CSRs, the L1 should include at least 20 % of CSRs in the selection window. Otherwise, the transmitter will do the procedure with a 3 dB increment in Th_{SPS} until 20 % target is met.

After forming the L1 list, the transmitter creates another list of CSRs, L2, which is a subset of L1 and includes exactly 20 % of the selection window CSRs with the lowest average Received Signal Strength Indicator (RSSI) over last ten intervals.

Finally, the transmitter randomly reserves one of the CSRs in L2 for its next R transmissions. This behavior helps avoid collisions between devices at the resource selection stage and gives more protection to devices using an SPS flow for transmission. In case the data cannot be fitted in the reserved subchannel(s), the transmitter should compete over the medium again. After each transmission, the reselection counter R is decremented by one. When it is equal to zero, additional resources should be selected and reserved with probability (1–P). Each vehicle can set-up P between zero and 0,8.

One-shot transmission is mainly used for critical event-based packet transmissions. However, it can be used for periodic packets as well. The resource selection procedure is exactly the same as SPS, but the transmitter does not reserve the selected resources for future transmission. This means that the reselection counter packet is zero in one shot transmission.

C.3.3 ProSe Per Packet Priority (PPPP) for V2X communication

In LTE-V2X, each packet generated by the application layer is associated with a certain priority value, called ProSe Per Packet Priority (PPPP). PPPP is an inter number and can range from 1 to 8 where packets with lower PPPP value have higher priority. PPPP can be used to determine Packet Delay Budget (PDB), Channel occupation Ratio (CR) limit, and RSRP threshold for accessing the channel.

C.4 SAMCO (Service-Actuated Multi-Channel Operation)

C.4.1 Introduction

In "Service-actuated multi-channel operation for vehicular communications" [i.27] by Mate Boban and Andreas Festag, the authors propose the MCO concept "SAMCO" that provides a logic to control the prioritization of services and the timing of channel switching. The algorithm designed in SAMCO takes into account user preferences to decide on which channel(s) the transceiver(s) need(s) to be tuned. It manages services depending on their level of priority, and it has the objective to minimize the channel switching frequency.

The concepts of a Data Provider (DP) and Data User (DU) roles are adopted to describe SAMCO entities. In short, DP is an entity (either a vehicle or an RSU) in charge of generating service advertisements and providing the service, while DU is the user/consumer of the service. While typically the DP transmits data to the DU, some services require the opposite directions of data traffic (e.g. a probe vehicle data service, where an RSU advertises the service and vehicles generate the data). Also, a bi-directional exchange between SP and users is possible. The latter is relevant when a service implies a reliable exchange of data between two vehicles, typically via unicast, e.g. for a make-space operation when a vehicle joins a platoon. In general, an entity can assume the DP and DU roles both concurrently and interchangeably (i.e. a vehicle providing a service would assume an DP role, and likewise it could assume an RSU role once it wants to consume a service).

The DP/DU concept represents a general framework for service provisioning in a vehicular network with MCO support, which covers a broad range of services for road safety, traffic efficiency and infotainment applications. In particular, the concept also includes specific services for vehicle automation and platooning, such as cooperative sensing and the exchange of manoeuvring commands.

C.4.2 Channel access strategy

In their paper, the authors assumed that each C-ITS-S has two transceivers. The first one is continuously listening to the CCH while the second one can dynamically switch between SCHs. Referring to the IEEE 1609.4-2016 document [i.26], the first transceiver would employ the continuous option while the second one would use the immediate one for the channel access strategy.

C.4.3 Channel usage possibilities

SAMCO assumes that SPs use the Service Announcement service on the CCH to inform other C-ITS-Ss on which channel which service is providing information. Furthermore, all DPs communicate their critical safety messages on the CCH while other services publish their information on one of the SCH.

To decide on which SCH the second transceiver needs to be tuned, the DUs rely on applications and user requirements.

For the DPs, the SCH selection depends on the CBR observed on the different channels. It is not feasible with one transceiver to collect the CBR on all SCHs while keep transmitting information on one SCH at the same time. To have an idea of the channel load on all SCHs, C-ITS-Ss exchange their perceived CBR with SAEMs. Based on the SAEMs received, DPs select the SCH with the lowest channel load to start transmitting their non-critical safety messages. After determining the SCH with the lowest CBR, an DP tunes its transceiver to the channel and checks if the CBR observed matches the one received by SAEMs.

If it is the case, the DP starts the transmission of its services to the SCH. Certain services might not need to provide the service on SCH before there are DUs that want to consume the service (e.g. platoon leader might announce, but not transmit a service before there are other vehicles in vicinity willing to join the platoon). Therefore, such services might require an DU to acknowledge consumption of the service. After one DU has acknowledged the consumption through a unicast message to DP, subsequent DUs consume the service without the need for acknowledgement. DUs are responsible to inform DPs of their message interests.

When the channel starts to be saturated, DPs stop publishing information of the services with the lower priority of all services publishing on the current SCH. If a DP stopped to publish information about all its services, it tries to reschedule its highest priority service stopped to another SCH.

C.5 IEEE 1609.4-2016

C.5.1 Introduction

The IEEE 1609.4-2016 Standard for WAVE about Multi-Channel Operation [i.26] specifies MAC sublayer functions and services to support multi-channel wireless connectivity between IEEE 802.11-2020 [i.108] WAVE devices. This standard defines an extension to the MAC sublayer management entity (MLME) specified in IEEE 802.11-2020 [i.108]. This includes time synchronization and channel access features in support of channel coordination, as well as channel-specific access to other IEEE 802.11-2020 [i.108] services, MIB maintenance, and readdressing.

Channel coordination is about supporting data exchanges involving one or more switching devices with concurrent alternating operation on multiple channels.

The time synchronization and channel access features specified in the IEEE 1609.4-2016 [i.26] standard is studied in clause C.5.2. Inputs and requirements for channel usage algorithm of the IEEE 1609.3-2016 [i.61] standard is discussed in clause C.5.3.

C.5.2 Channel access strategy

Each transceiver of the WAVE devices has different possible channel access options: continuous, alternating, and immediate channel access, as exemplified in Figure C.5.2-1.

The descriptions of the different channel access options are:

- **Continuous option:** the designated channel is available for an indefinite duration.
- **Alternating option:** the transceiver is repetitively tuned to a channel for a time slot 0, and then is switched to another channel for a time slot 1. The duration of the time slots 0 and 1 is set to 50 ms in the standard (see Annex H in [i.26]).
- **Immediate option:** immediate access allows immediate communications access on a designated channel for an extended period without consideration for time slot boundaries.

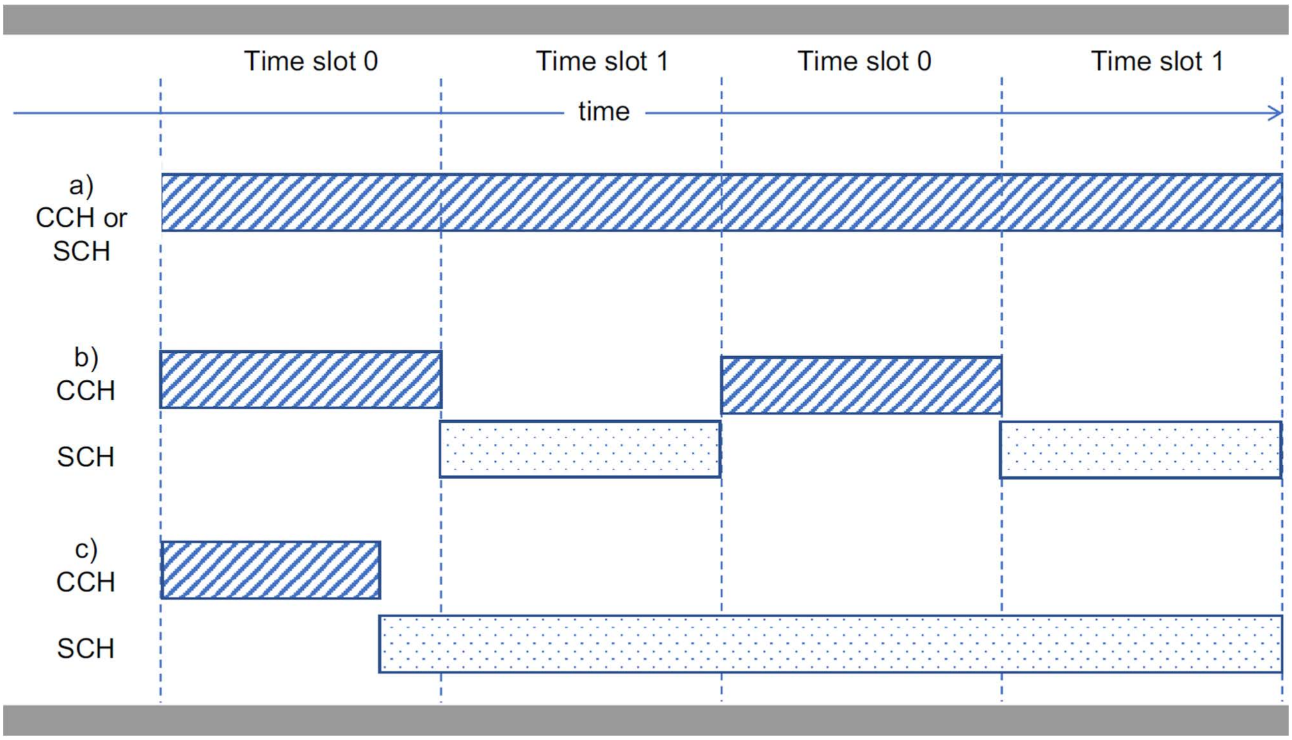


Figure C.5.2-1: Channel access examples:
(a) continuous, (b) alternating, and (c) immediate

To support the different channel access options, WAVE devices should synchronize to a common time base, especially when WAVE devices are switching channels on time slot boundaries such as in the alternating channel access option. The timing information used for synchronization may be derived by a timing management function from information received over the air from the other WAVE devices or may be obtained from a local source.

Each time slot includes an initial guard interval, which is used to account for radio switching effects and timing inaccuracies among different devices. During the guard interval, a switching device might not be available for communication, as its switching PHY could be in a transition state between channels. For a device switching channels on time slot boundaries, at the beginning of a guard interval the MAC transmit/receive activities on the previous channel may be suspended; at the end of the guard interval the transmit/receive activities on the next channel should be started or resumed if they were suspended. To prevent multiple switching devices from attempting to transmit simultaneously at the end of a guard interval, a device switching to a channel during the guard interval should declare medium busy (specified in IEEE 802.11-2020 [i.108]) during that guard interval so that its transmission attempts are subject to a random back-off when the guard interval ends. A device using alternating channel access should declare medium busy during each guard interval in which it switches. The length of the guard interval is set to 4 ms in [i.26].

C.5.3 Channel usage strategy

The IEEE 1609.3-2016 standard for WAVE about Networking Services [i.61] does not provide an algorithm to assign channel to services. However, the standard defines roles and criteria to realize such algorithm.

For convenience, two WAVE device roles are defined. The provider role is assumed by a device transmitting WAVE Service Advertisements (WSAs) indicating its availability for data exchange on one or more channels. The user role is assumed by a device monitoring for received WSAs, with the potential to participate in a data exchange on any channel. A WAVE device may assume one, both, or neither role. WSA may be transmitted on any channel and during any time slot but are nominally sent on the CCH during time slot 0.

To elaborate an algorithm to assign channel to services, the following criteria should be considered by algorithm developers:

- Number of channels that can be simultaneously accessed by the device's radio equipment
- Service requests

- Available services matching user service requests
- The relative priorities of the requested services
- The Channel Access of the application-service, i.e. the time slots during which it is active

In general, the access assignment algorithm may give precedence to requests with higher priority. Channel service requests with a higher priority may take precedence over lower priority assignments that would interfere with ongoing channel operation. For example, SCH access in support of a user service request may be assigned but without the requested immediate access.

Other factors may be considered, such as the following:

- The geographic proximity to the transmitter of the WSA
- Link quality associated with the transmitter of the WSA
- Application-service duration

After channel access has been assigned, certain events such as the following should cause the assignment to be ended:

- Application-service has been deleted
- User service request no longer matching an available application-service opportunity, i.e. there is no WAVE device offering the service wanted by the user
- Need to satisfy a service request with higher priority
- Loss of lower layer synchronization
- Other factors, such as poor Link Quality

Annex D: Insight in the channel models

D.1 Introduction

Several channel models have been proposed in the literature. Among them, the WINNER+ B1 is one of the most used, which appears suitable for an urban scenario, but not for a highway scenario. In this annex, some the main channel models are recalled and compared to motivate the choices in clause 8. All calculations assume a carrier frequency of 5,9 GHz. The analysis is limited to LOS conditions.

D.2 WINNER+ B1, C1, C2 path-loss models in LOS conditions

The WINNER+ scenarios B1 (urban microcell), C1 (suburban macrocell), and C2 (urban macrocell) are here considered [i.21]. Height of 1,5 m for both the transmitter and receiver antennas are assumed in all cases.

Specifically, the pathloss in the case of WINNER+ scenarios B1 (urban microcell), LOS, is as follows:

$$PL_{dB}(d) = \begin{cases} 42{,}42 + 22{,}7\log_{10}(d) & if\ d \le d_{T0} \\ 20{,}05 + 40{,}0\log_{10}(d) & otherwise \end{cases}$$

where $d_{T0} = 19{,}67$ m is the breakpoint distance.

The pathloss in the case of WINNER+ scenarios C1 (suburban microcell), LOS, is as follows:

$$PL_{dB}(d) = \begin{cases} 42{,}62 + 23{,}8\log_{10}(d) & if\ d \le d_{T0} \\ 6{,}22 + 40{,}0\log_{10}(d) & otherwise \end{cases}$$

where $d_{T0} = 177$ m is the breakpoint distance.

The pathloss in the case of WINNER+ scenarios C2 (suburban macrocell), LOS, is as follows:

$$PL_{dB}(d) = \begin{cases} 40{,}42 + 26{,}0\log_{10}(d) & if\ d \le d_{T0} \\ 22{,}32 + 40{,}0\log_{10}(d) & otherwise \end{cases}$$

where $d_{T0} = 19{,}67$ m is the breakpoint distance.

D.3 Modified versions of the path-loss models in ECC REPORT 68

The following channel models are modified versions of those detailed in the ECC REPORT 68 [i.105].

As already reported in clause 8, the modification, compared to the original ECC Report 68 [i.105], is in smaller values for the breakpoint distances. The rational is that the original models in ECC Report 68 [i.105] have been developed for the link between a device, with height 1,5 m, and an access point, with height 10 m to 25 m (the addressed technologies were BWA systems, such as WiMax®).

Specifically, the modified ECC 68 path-loss models are calculated as follows:

$$PL_{dB}(d) = \begin{cases} 20\log_{10}\left(\frac{\lambda}{4\mu d}\right) & if\ d \le d_{T0} \\ 20\log_{10}\left(\frac{\lambda}{4\mu d_{T0}}\right) - 10n_0\log_{10}\left(\frac{d}{d_{T0}}\right) & if\ d_{T0} < d \le d_{T1} \\ 20\log_{10}\left(\frac{\lambda}{4\mu d_{T0}}\right) - 10n_0\log_{10}\left(\frac{d_{T1}}{d_{T0}}\right) - 10n_1\log_{10}\left(\frac{d}{d_{T1}}\right) & otherwise \end{cases}$$

where d_{T0} is the first breakpoint distance, n_0 is the path loss factor beyond the first breakpoint distance, d_{T1} is the second breakpoint distance, n_1 is the path loss factor beyond the second breakpoint distance.

In the urban scenario, $d_{T0} = 32$ m, $n_0 = 3{,}8$, $d_{T1} = 64$ m, and $n_1 = 4{,}3$.

In the suburban scenario, $d_{T0} = 64$ m, $n_0 = 3{,}3$, $d_{T1} = 128$ m, and $n_1 = 3{,}8$.

Finally, in the rural scenario, $d_{T0} = 128$ m, $n_0 = 2{,}8$, $d_{T1} = 512$ m, and $n_1 = 3{,}3$.

D.4 LOS path-loss model in ETSI TR 103 257-1

Also, in ETSI TR 103 257-1 [i.24] path-loss models are provided.

The path-loss model in urban scenarios with LOS conditions is as follows:

$$PL_{dB}(d) = 52{,}80 + 16{,}7\log_{10}(d).$$

The path-loss model in highway scenarios with LOS conditions is as follows:

$$PL_{dB}(d) = 47{,}82 + 20\log_{10}(d).$$

D.5 Comparison of the LOS path-loss models

In Figure D.5-1 and Figure D.5-2, a comparison is provided in terms of path-loss varying the transmitter-receiver distance, for the urban and non-urban scenarios, respectively. In the case of non-urban scenario, also the WINNER+, model B1, which is defined for urban microcell scenarios, is shown, since it is often used for highway scenarios in the literature.

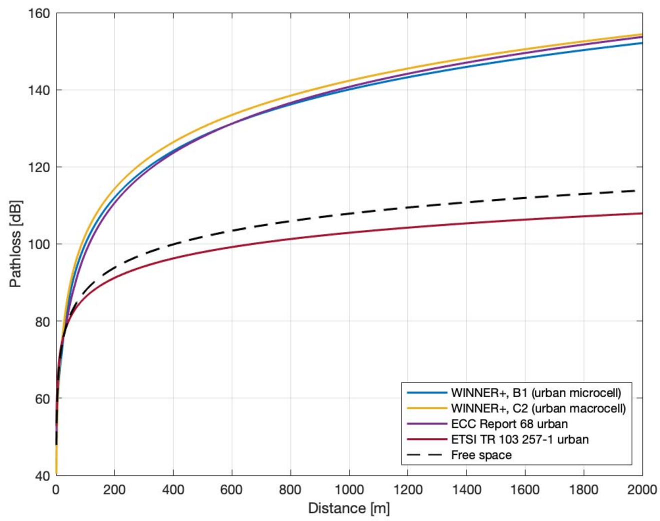


Figure D.5-1: Path-loss vs. transmitter-receiver distance for a number of models designed for the urban scenario

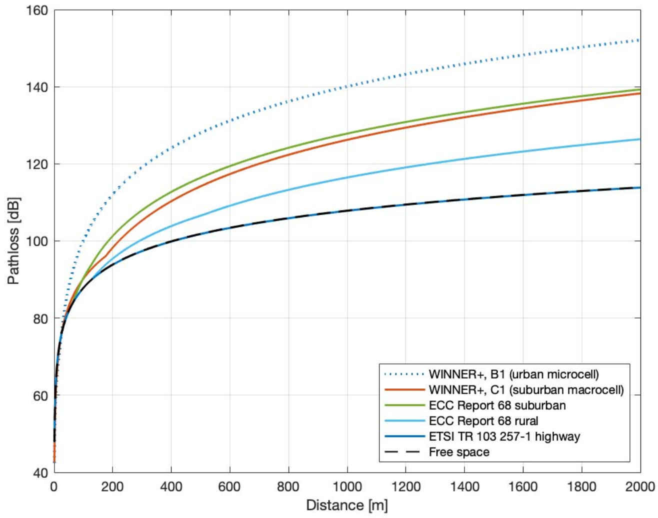


Figure D.5-2: Path-loss vs. transmitter-receiver distance for a number of models designed for the highway scenario

Annex E: Impact of the interference from adjacent channels: additional results

E.1 Introduction

In this annex, additional results are reported for the case detailed in clause 8.5.2, where balanced traffic is supposed over two channels.

Similarly to clause 8.5.2, given the scenarios and settings detailed in clauses 8.4.2 and 8.4.3, here simulation results are provided assuming that half of the vehicles act in one channel and the other half in one of the other channels (1st or 2nd adjacent channel). Results assuming a single channel, with either half or all of the vehicles are also provided.

E.2 Inter-packet gap detailed statistics

Hereafter, the ccdf of IPG of the simulations detailed in clause 8.5.2 are provided. Summary results from these curves were shown in clause 8.5.3.5, focusing only on the values corresponding to a ccdf equal to 0,1.

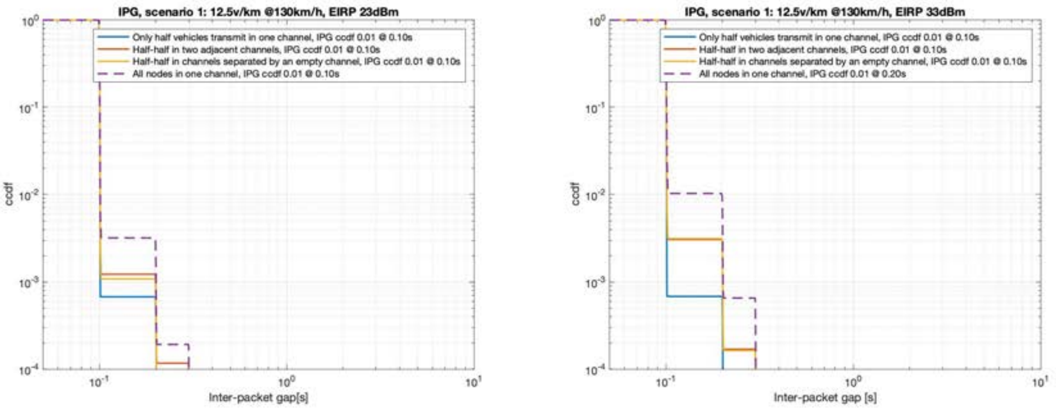


Figure E.2-1: Balanced traffic. ccdf of IPG in scenario 1

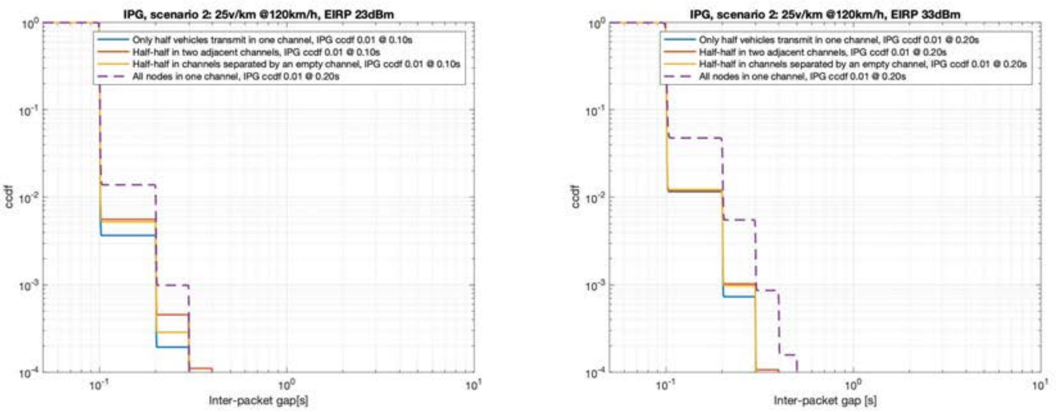


Figure E.2-2: Balanced traffic. ccdf of IPG in scenario 2

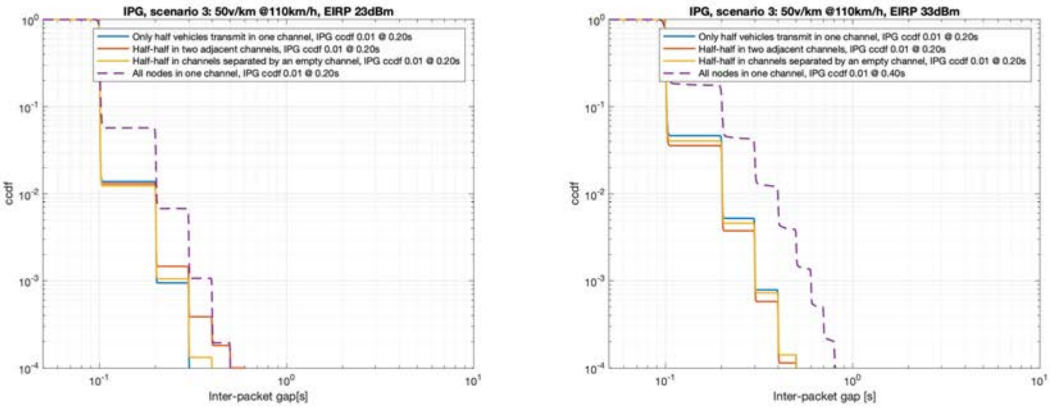


Figure E.2-3: Balanced traffic. ccdf of IPG in scenario 3

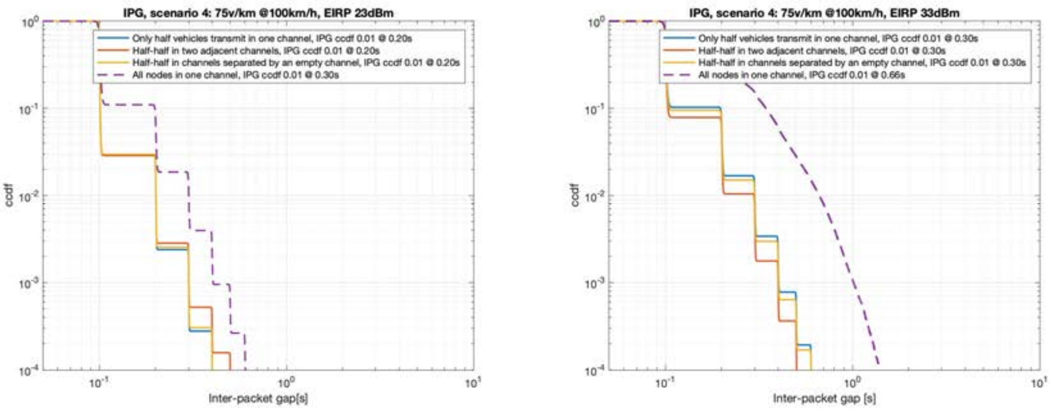


Figure E.2-4: Balanced traffic. ccdf of IPG in scenario 4

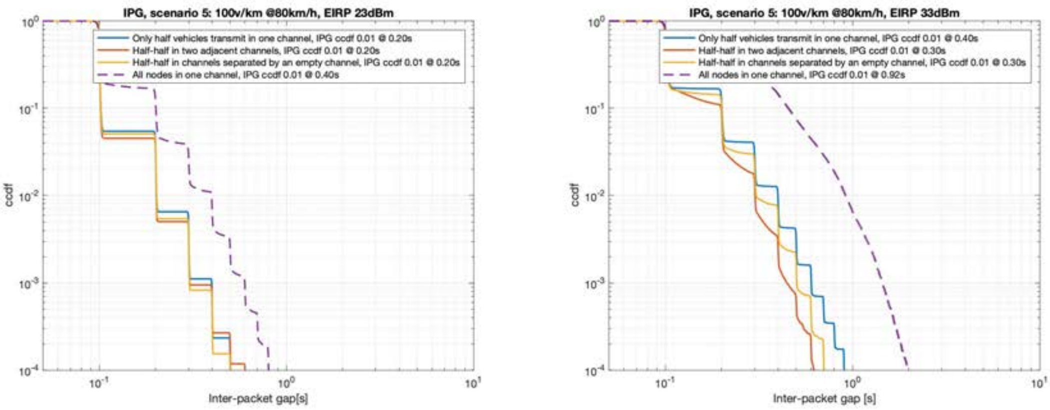


Figure E.2-5: Balanced traffic. ccdf of IPG in scenario 5

E.3 Results assuming a different channel model

In this clause, a different channel model is assumed, i.e. WINNER+, scenario B1 LOS [i.21]. Despite the fact that it was derived for urban microcells, it is one of the mostly adopted models also for highway scenarios. In this annex, it is used to verify that the derived conclusions are valid besides the specific channel model.

The WINNER+, Scenario B1 LOS model (or simply WINNER+ in the present document), is a two-slope channel model with exponent 4 above approximately 20 m, which is compared to the free space and the ECC 68 rural models in Figure E.3-1.

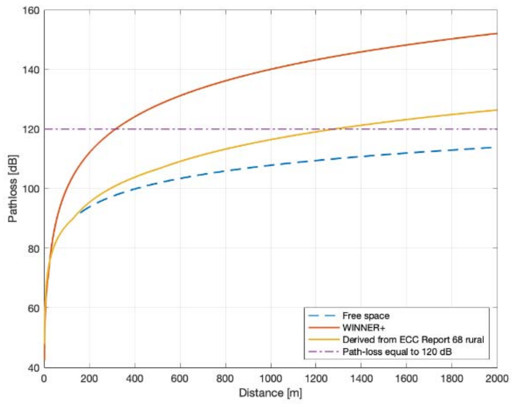


Figure E.3-1: Path loss vs. distance with different models

Given that the expected range with the WINNER+ B1 model is approximately one fourth of the one obtained with the ECC68 rural model, referring to a path loss value of 120 dB, hereafter we consider scenarios with a higher density of vehicles compared to clause 8.5.2.

Specifically, a straight road with 6 lanes, corresponding to 3 lanes in each direction of 4 m width, is considered. The length of the highway is here 2 km. The following five vehicle densities with different average vehicle speed are considered (the average inter-vehicle distance is approximately 2,5 s multiplied by the average vehicle speed):

- Scenario A: 35 vehicles/km at 250 km/h;
- Scenario B: 61,5 vehicles/km at 140 km/h;
- Scenario C: 166,5 vehicles/km at 50 km/h;
- Scenario D: 333 vehicles/km at 25 km/h;
- Scenario E: 500 vehicles/km at 15 km/h.

The initial position and movements of the vehicles are generated as described in clause 8.3.

Selected results, in terms of PRR, are shown in Figure E.3-2, Figure E.3-3, and Figure E.3-4.

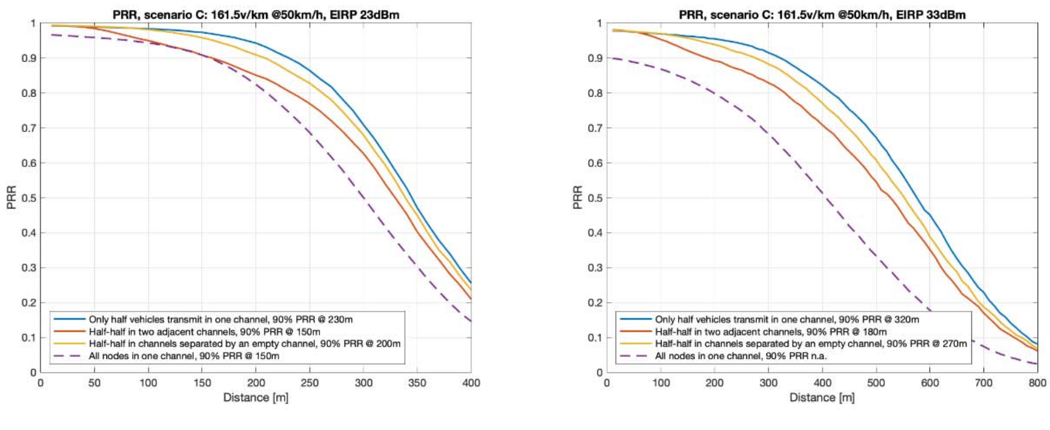


Figure E.3-2: Highway scenario with Winner+, B1. PRR vs. distance in scenario C

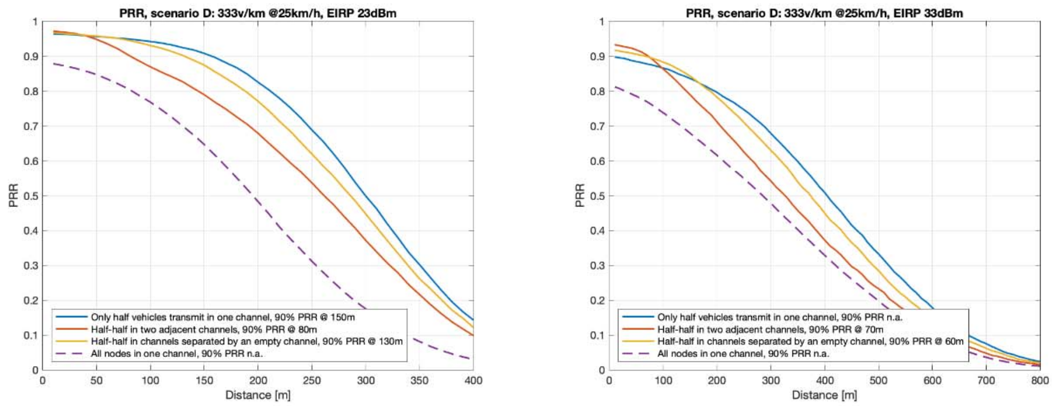


Figure E.3-3: Highway scenario with Winner+, B1. PRR vs. distance in scenario D

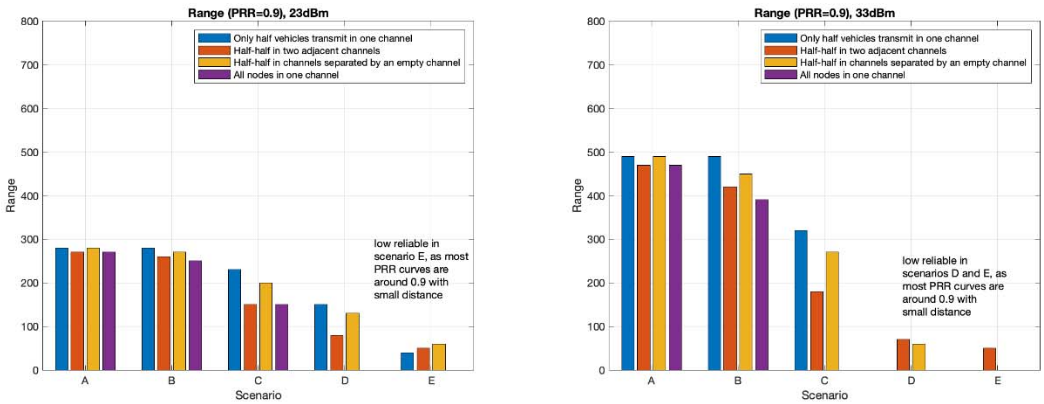


Figure E.3-4: Highway scenario with Winner+, B1. Range (maximum distance with PRR = 0,9)

As it can be observed looking at Figure 25, Figure 26, and Figure 28, despite the different model and taking into account a scale factor in the density due to the different range, the conclusions are very similar to those provided in clause 8.5.2. This implies that the derived observations are of wide validity and are not limited to the specific channel model that was adopted.

OBSERVATION: The observations provided in clause 8.5.2.6 are not limited to a specific channel model.

E.4 Results assuming messages with a larger size

In Figure E.4-1, Figure E.4-2, and Figure E.4-3, results adopting packets of 550 bytes are shown.

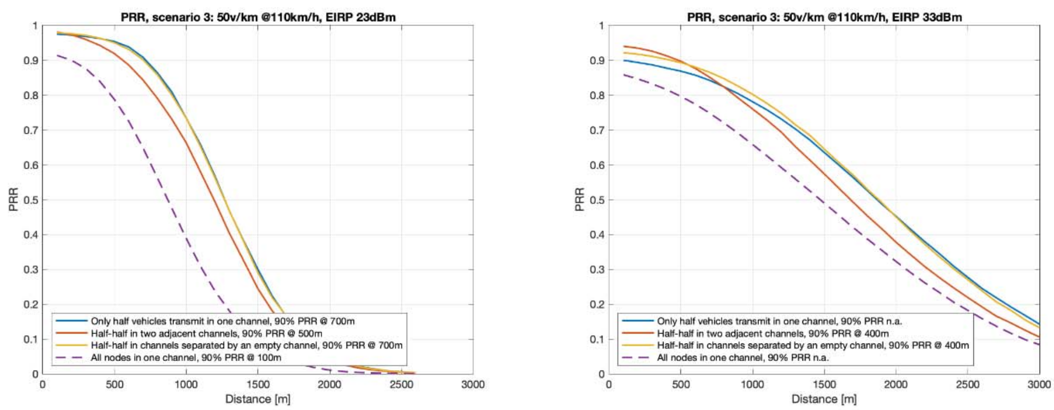


Figure E.4-1: PRR vs. distance in scenario 3 with packets of 550 bytes

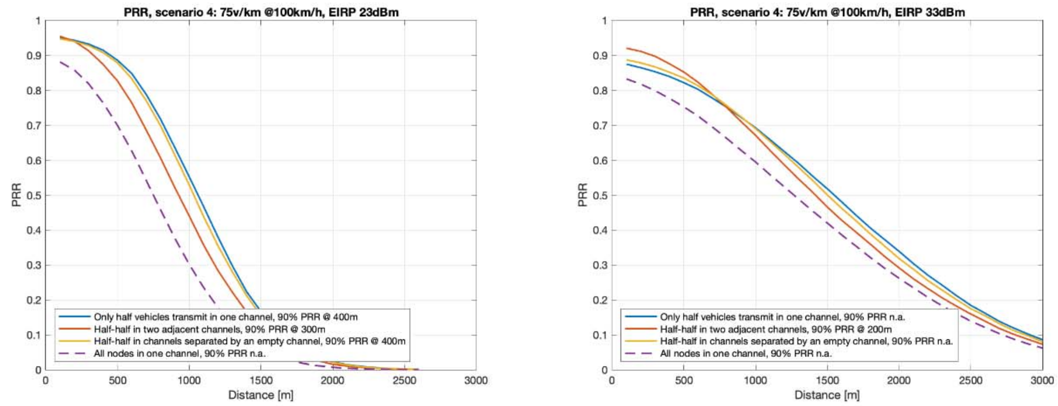


Figure E.4-2: PRR vs. distance in scenario 4 with packets of 550 bytes

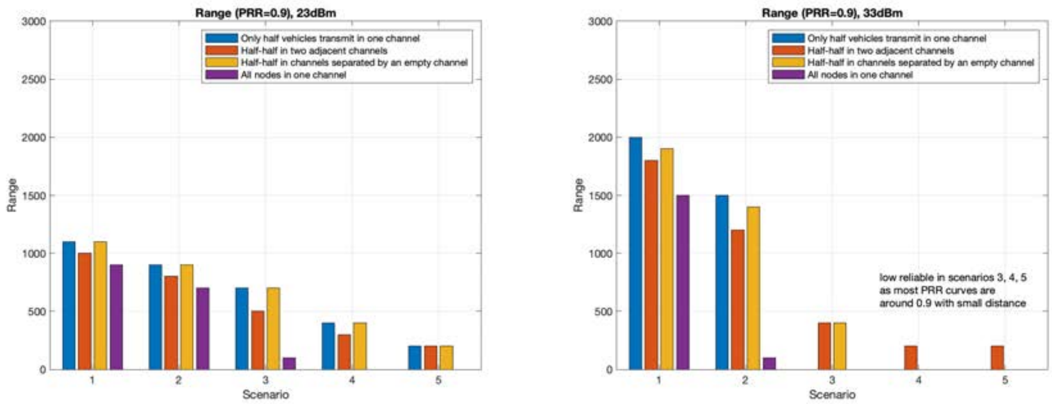


Figure E.4-3: Range (maximum distance with PRR = 0,9) with packets of 550 bytes

As expected given the longer length of the packets, the PRR observed in Figure E.4-1, Figure E.4-2, and Figure E.4-3 (550 bytes) is lower than the one shown in Figure 25, Figure 26, and Figure 28, respectively (350 bytes). However, the observations provided in clause 8.5.2 remain valid. This implies that the derived observations are of wide validity and are not constrained to the specific packet size that was adopted.

OBSERVATION: The observations provided in clause 8.5.2.6 are not limited to a specific packet size.

E.5 Results in urban scenarios

In this clause, results in urban scenarios are shown.

In the urban scenario vehicles are moving along perpendicular roads separated by blocks of buildings. This topology is known as a Manhattan grid. Non-Line Of Sight (NLOS) links between vehicles around the corners are considered.

The scenario is composed by 2 × 2 blocks, creating a grid of roads with intersections. Each block is formed by a building, with two lanes 3,5 m wide all around it; the direction of movement around the building is clockwise defined. The composition of more than one block creates roads with 4 lanes per road, 2 per direction, as exemplified in Figure E.5-1. Each block is 250 m large and 433 m long.

Two scenarios are considered with different number of vehicles and average speed on the road (the average inter-vehicle distance is approximately 2,5 s multiplied by the average vehicle speed):

- Scenario 6: Urban A, with 65 vehicles per block at average 60 km/h;
- Scenario 7: Urban B, with 130 vehicles per block at average 30 km/h.

The initial position of the vehicles is evenly distributed over the lanes and uniformly distributed over the road length (approximating a Poisson distribution). Vehicles reaching an intersection will move forward with probability 0,5, turn left with probability 0,25, and turn right with probability 0,25 (uniformly distributed)); they will maintain the corresponding lane in the new road. Vehicles exiting the scenario will enter again the scenario on the same road, same lane, at the opposite side (wrap around approach).

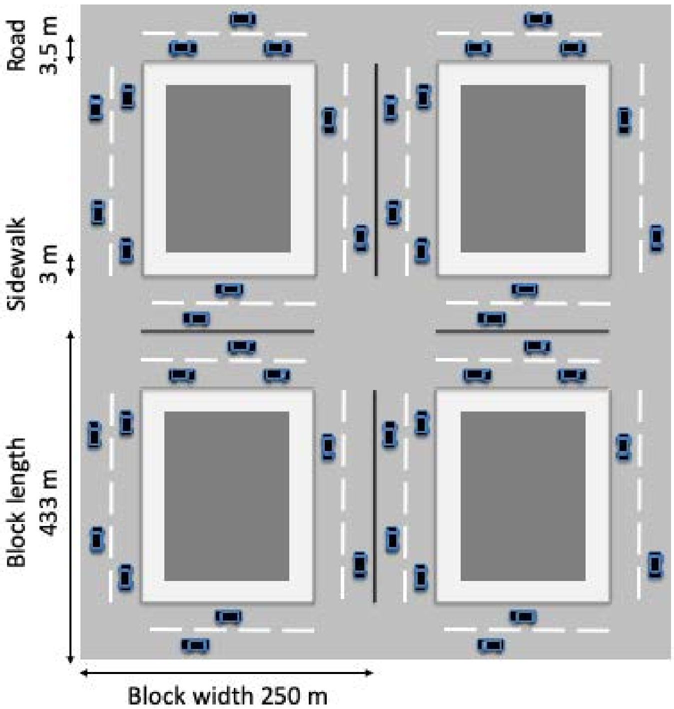


Figure E.5-1: Urban scenarios

As channel propagation model, the WINNER+, scenario B1, either LOS or Manhattan NLOS, is used. Correlated log-normally distributed large-scale fading (shadowing) is considered, with 10 m decorrelation distance.

In the urban scenarios, link-level curves relating the SINR to the PER were obtained with the same assumptions detailed in clause 8.4.4.4 but adopting the urban LOS and urban NLOS fading models detailed in ETSI TR 103 257-1 [i.24].

Results in the urban scenario are shown in Figure E.5-2, Figure E.5-3 and Figure E.5-4.

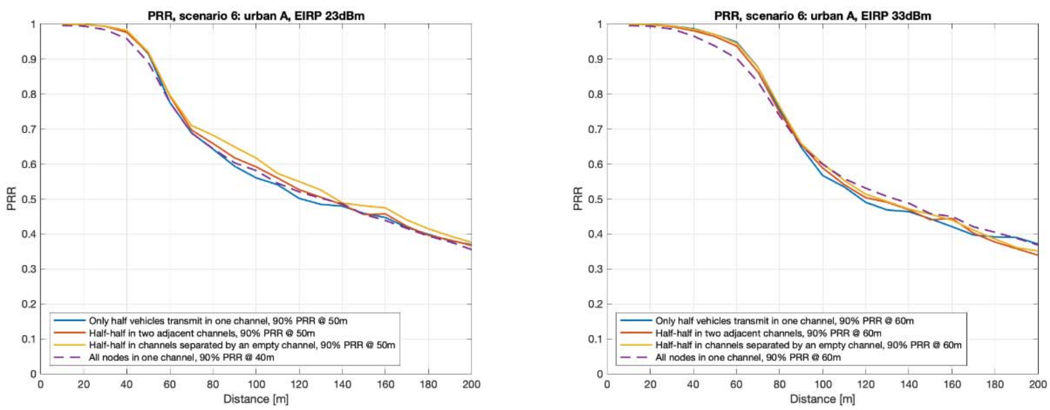


Figure E.5-2: PRR vs. distance in scenario 6 (urban A)

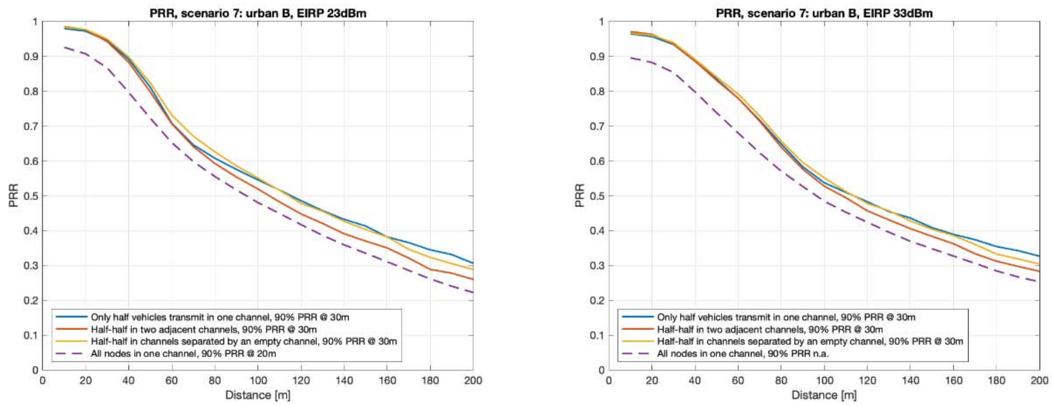


Figure E.5-3: PRR vs. distance in scenario 7 (urban B)

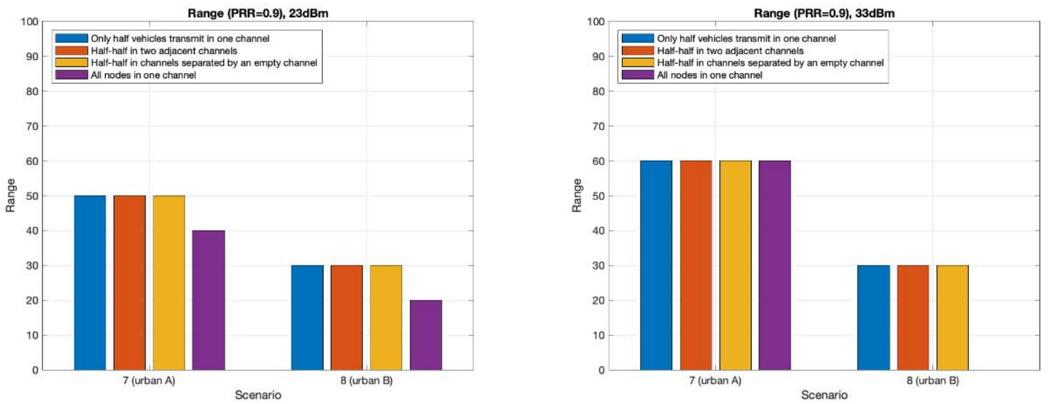


Figure E.5-4: Range (maximum distance with PRR = 0,9) in the urban scenarios

Observing the results shown in Figure E.5-2, Figure E.5-3 and Figure E.5-4, it appears clear that the NLOS conditions have a radical impact on the PRR. It is confirmed that the interference from adjacent channels does not significantly degrade the performance in the reference channel. In all cases, distributing the data traffic over two channels allows to obtain better performance than having all the data traffic in a single channel.

OBSERVATION: The observations provided in clause 8.5.2.6 are not limited to the highway scenario.

Annex F: Interference from SRD to ITS-G5 in non-safety channels

F.1 Introduction

This annex discusses, focusing on a use case of particular relevance, the impact of signals transmitted by SRDs in non-safety channels to ITS-G5 based communications.

In particular, the investigation refers to the impact on ITS-G5 transmitters and receivers from an SRD which is transmitting from the inside of a building adopting the same channel. This scenario appears as a common situation and thus corresponds to a case of particular relevance.

F.2 Scenario and assumptions

An SRD is assumed to continuously transmit from the inside of a building with an EIRP of 14 dBm in a 10 MHz channel fully overlapping with an ITS channel. It is also assumed that the SRD always transmits with the main beam towards the C-ITS-S. The continuous transmission with the main beam in the direction of the C-ITS-S represents a worst case.

The SRD transmits in the same channel as the ITS-G5 C-ITS-Ss. The SRD is assumed at least 20 m far from the vehicles driving on the road, with a 17 dB indoor-to-outdoor attenuation.

The antenna gain at the C-ITS-S receiver is assumed of 3 dBi.

Either WINNER+ scenario B1 or ECC 68 rural are considered for the path-loss, which are detailed in Annex D. Only a distance-based average path-loss is considered.

F.3 Impact of interference

The impact is separately observed from the perspective of the transmitting C-ITS-S and from the perspective of the receiving C-ITS-S.

Focusing on the transmitting C-ITS-S and given the settings specified in clause F.2, the power received from the SRD interferer at the minimum distance (i.e. 20 m) is 72,1 dB assuming WINNER+ scenario B1 and 73,88 assuming ECC 68 rural. The received power is thus always below the carrier sensing threshold used to consider the channel as busy when the signal is not decodable, which corresponds to -65 dBm. This implies that the CSMA/CA protocol never differs the transmission due to the interference from SRD.

At the same time, the received power at the minimum distance is above the threshold used for CBR assessment, which is set to -85 dBm. Based on the settings detailed in clause F.2, the received signal is above the threshold for a road segment of approximately 80 m assuming WINNER+ scenario B1 and 150 m assuming ECC 68 rural. Along that road segment, the SRD signal contributes to the CBR calculation and might cause limitations to the transmissions from the C-ITS-S.

Focusing on the receiving C-ITS-S, given the same settings, approximating the interference as summable to the noise, and approximating the two path-loss models to a single-slope model of the kind kd^{β} with exponent β=4 in the case of WINNER+ scenario B1 (valid above 20 m) and 2,8 in the case of modified ECC report 68 (valid between 128 and 512 m), it can be written that the SINR at a given distance d is equal to $SINR = \frac{P_t/kd^{\beta}}{P_N+P_I}$, where P_t is the transmission power, P_N is the noise power, and P_I is the interfering power. If a fixed SINR is considered, comparing the case with or without interference from the SRD, denoted as P_{SRD}, which is the only source of interference, the range loss ρ, from a distance reached without SRD interference d_{ref} to a distance with SRD interference d_{interf}, can be calculated as:

$$\rho = \frac{d_{ref}-d_{interf}}{d_{ref}} = 1 - \frac{d_{interf}}{d_{ref}} = 1 - \left(\frac{P_N}{P_N+P_I}\right)^{\frac{1}{\beta}}.$$

Assuming noise power equal to -98 dBm (corresponding to a noise figure of 6 dB) and SRD interfering power depending on the position of the C-ITS-S receiver which is moving on a straight road, the range loss varying the distance of the vehicle from the worse position is shown in Figure F.3-1. With worse position it is meant the position where the C-ITS-S is 20 m from the SRD; the x-axis thus reflects the placement of the vehicle over the road segment rather than the air-distance from the SRD.

As observable, assuming the ECC 68 rural model, which is the worst case in this investigation, the range loss is between 80-90 % near to the SRD, goes below 50 % at approximately 150 m from the worst position, and falls below 10 % at nearly 350 m from the worst position.

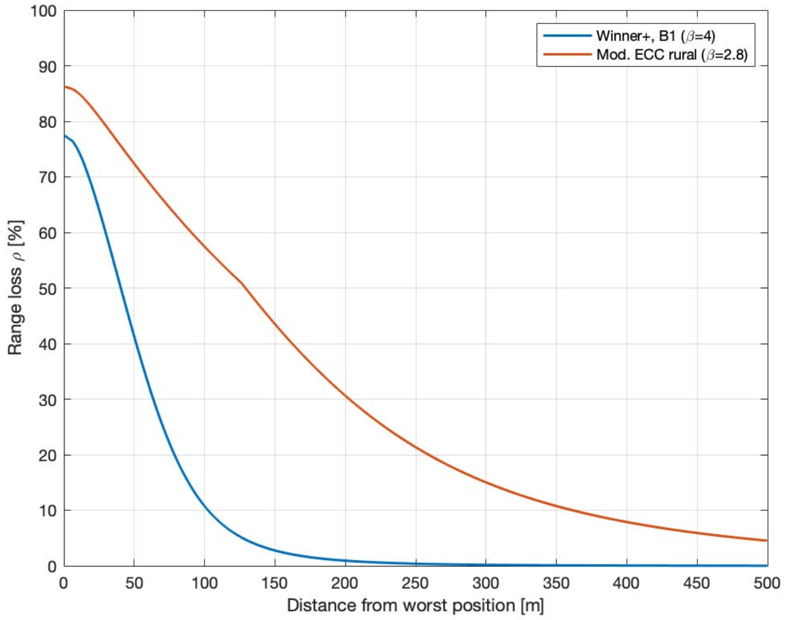


Figure F.3-1: Range loss varying the distance of the vehicle from the position at minimum distance from the SRD

As a summary, the following observations apply:

OBSERVATION: The interference from the indoor SRD does not appear critical at ITS-G5 transmitter during the channel busy assessment process of CSMA/CA.

OBSERVATION: The interference from the indoor SRD can increase the CBR estimation of the ITS-G5 station in the proximity. This might cause the station to reduce the generated traffic also in the absence of other ITS-G5 C-ITS-Ss.

OBSERVATION: The interference from the indoor SRD can cause a significant range loss, which appears however limited to the close proximity.

Annex G: Interference from SRD to LTE-V2X in non-safety channels

G.1 Introduction

This annex discusses the impact of signals transmitted by SRDs in non-safety channels to LTE-V2X based communications. In particular, the investigation refers to the impact on LTE-V2X transmitters and receivers from an SRD which is transmitting from the inside of a building adopting the same channel. This is the same scenario investigated in Annex F, however focusing on LTE-V2X instead of ITS-G5.

G.2 Scenario and assumptions

An SRD is assumed to continuously transmit from the inside of a building with an EIRP of 14 dBm. It is also assumed that the SRD always transmits with the main beam towards the LTE-V2X C-ITS-S. The continuous transmission with the main beam in the direction of the LTE-V2X C-ITS-S represents a worst case.

The SRD transmits with a bandwidth of 10 MHz in the same channel as the LTE-V2X C-ITS-S. The SRD is assumed at least 20 m far from the vehicles driving on the road, with a 17 dB indoor-to-outdoor attenuation.

The antenna gain at the LTE-V2X C-ITS-S receiver is assumed of 3 dBi.

Either WINNER+ scenario B1 or ECC 68 rural are considered for the path-loss, which are detailed in Annex D. Only a distance-based average path-loss is considered.

G.3 Impact of interference

The impact is separately observed from the perspective of the transmitting LTE-V2X C-ITS-S and from the perspective of the receiving LTE-V2X C-ITS-S.

Focusing on the transmitting LTE-V2X C-ITS-S and given the settings specified in clause G.2, the power received from the SRD interferer at the minimum distance (i.e. 20 m) is -71,97 dBm assuming WINNER+ scenario B1 and -73,88 dBm assuming ECC 68 rural. The resources exclusion in the Semi Persistent Scheduling (SPS) algorithm of LTE-V2X works in two steps. In the first step, based on decoded control information, resources which are currently allocated to other stations will be excluded from the candidate resources list if the reference signal received power (RSRP) is above a threshold. This threshold will be increased by 3 dB until at least 20 % of the candidate resources are remaining. In the second step, the average Received Signal Strength Indicator RSSI is used to down select exactly 20 % of the resources with the lowest RSSI leading to the random selection of one of the remaining resources. Therefore, as a consequence of the continuous transmission from the SRD, the RSSI increase caused by its interference SRD will not impact the SPS of LTE-V2X at all.

The threshold used for CBR assessment is set to -94 dBm per subchannel according to ETSI TS 103 574 [i.20]. This corresponds to a received interference power of -87 dBm for the full bandwidth and therefore the received power at the minimum distance is above this threshold. Based on the settings detailed in clause G.2, the received signal is above the threshold for a road segment of approximately 90 m assuming WINNER+ scenario B1 and 180 m assuming ECC 68 rural. Along that road segment, the SRD signal contributes to the CBR calculation and might cause limitations to the transmissions from the LTE-V2X C-ITS-S.

For the receiving LTE-V2X station the observations for the range loss due to the SINR degradation can be applied according to clause F.3 directly to LTE-V2X.

As a summary, the following observations apply.

OBSERVATION: The interference from continuous transmission by indoor SRD does not appear critical at an LTE-V2X transmitter for the Semi Persistent Scheduling. The impact with a discontinuous transmission from the SRD needs further studies.

OBSERVATION: The interference from the indoor SRD can increase the CBR estimation of the LTE-V2X station in the proximity. This might cause the station to reduce the generated traffic due to a higher CR limit.

OBSERVATION: The interference from the indoor SRD can cause a significant range loss, which appears however limited to the close proximity.

Annex H: Bibliography

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History

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