ETSI TR 103 562 V2.1.1 (2019-12)

TECHNICAL REPORT

Intelligent Transport Systems (ITS);
Vehicular Communications;
Basic Set of Applications;
Analysis of the Collective Perception Service (CPS);
Release 2

Reference
DTR/ITS-00183

Keywords
ITS, network, protocol

ETSI

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Foreword

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

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Introduction

The Collective Perception Service aims at enabling ITS-Ss to share information about other road users and obstacles that were detected by local perception sensors such as radars, cameras and alike. In that sense, it aims at increasing awareness between ITS-Ss by mutually contributing information about their perceived objects to the individual knowledge base of the ITS-S. The service does not differentiate between detecting connected or non-connected road users.

The service defines the Collective Perception Message (CPM) which allows for sharing of information about detected objects by the disseminating ITS-S. The message consists of information about the disseminating ITS-S, its sensory capabilities and its detected objects. For this purpose, the message provides generic data elements to describe detected objects in the reference frame of the disseminating ITS-S. The CPM is transmitted cyclically with adaptive message generation rates to decrease the resulting channel load while focusing on reporting changes in the dynamic road environment.

The present document represents the analysis for the service and to derive its requirements for future standardization activities.

1 Scope

The present document prepares the specification of the Collective Perception Service [i.1] to support applications in the domain of road and traffic safety applications. Collective Perception aims at sharing information about the current driving environment with other ITS-Ss. For this purpose, the Collective Perception Service provides data about detected objects (i.e. other road participants, obstacles and alike). Collective Perception reduces the ambient uncertainty of an ITS-S about its current environment, as other ITS-Ss contribute context information. This includes the definition of the syntax and semantics of the Collective Perception Service (CPS) and detailed description of the data, the messages and the message handling to increase the awareness of the environment in a cooperative manner.

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.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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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:

Collective Perception (CP): concept of sharing the perceived environment of a station based on perception sensors

NOTE: In contrast to Cooperative Awareness (CA), an ITS-S broadcasts information about its current (driving) environment rather than about its current state. Hence, CP is the concept of actively exchanging locally perceived objects between different ITS-Ss by means of V2X communication technology. CP decreases the ambient uncertainty of ITS-Ss by contributing information to their mutual Field-of-Views.

Collective Perception (CP) Basic Service: facility at the ITS-S facilities layer to generate, receive and process CPM

Collective Perception Message (CPM): CP basic service PDU

Collective Perception (CPM) protocol: ITS facilities layer protocol for the operation of the CPM transmission and reception

environment model: current computational representation of the immediate environment of an ITS-S, including all perceived objects detected by either local perception sensors or received by V2X

ITS Central System: ITS system in the backend, such as traffic control centre, traffic management centre, or cloud system from road authorities, ITS application suppliers or automotive OEMs

NOTE: See clause 4.5.1.1 of ETSI EN 302 665 [i.9].

object: state space representation of a physically detected object within a sensor's perception range

object list: collection of objects temporally aligned to the same timestamp

sensor measurement: measurement of a local perception sensor mounted to a station whereby a feature extraction algorithm provides object position and attitude descriptions

NOTE: The feature extraction algorithm processes a sensor's raw data (e.g. reflection images, camera images, etc.) to generate an object's state space representation description.

state space representation: mathematical description of a detected object

NOTE: It consists of state variables such as distance, speed, object dimensions, etc. The state variables associated to an object are interpreted as an observation for a certain point in time and are therefore always accompanied by a time reference.

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

3.2 Symbols

Void.

3.3 Abbreviations

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

ASN.1	Abstract Syntax Notation One
BTP	Basic Transport Protocol
CA	Cooperative Awareness
CAM	Cooperative Awareness Message
CBR	Channel Busy Ratio
CCH	Control CHannel

CP	Collective Perception
CPM	Collective Perception Message
CPS	Collective Perception Service
DCC	Decentralized Congestion Control
DE	Data Element
DF	Data Frame
DP	DCC Profile
EDCA	Enhanced Distributed Channel Access
I2V	Infrastructure to Vehicle
ITS	Intelligent Transport Systems
ITS-S	Intelligent Transport Systems-Station
LOS	Line Of Sight
MAP	MAPdata messages
MCO	Multi Channel Operations
MCS	Modulation and Coding Scheme
MTU	Maximum Transmission Unit
N2V	Network to Vehicle
OEM	Original Equipment Manufacturer
P2I	Person to Infrastructure
P2N	Person to Network
P2V	Person to Vehicle
PDF	Probability Density Function
PDR	Packet Delivery Ratio
PDU	Packet Data Unit
PER	Packed Encoding Rules
RSU	RoadSide Unit
SCO	Single Channel Operations
SUMO	Simulation of Urban MObility
TRC	Transmit Rate Control
UPER	Unaligned Packed Encoding Rule
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VRU	Vulnerable Road User

4 The Concept of Collective Perception

4.1 Background and Use-Cases

4.1.1 Introduction

The CP message offers ITS stations the possibility to share information about objects in the surrounding, which have been detected by sensors, cameras or other information sources mounted to the transmitting traffic participant. In the following clauses, some exemplary use cases are described, for which CP service is beneficial.

4.1.2 Detection of Non-Connected Road Users

Use Case Name	Detection of Non-Connected Road Users.
Category	Safety.
Short Description	Road users, which are not able to communicate themselves, can only be perceived by other road users' environment perception sensors. In this case, the awareness range is limited to the field of the view of the sensors, which is especially critical for objects shadowed by buildings, cars and other obstacles. With the CP service, the number of road users which are recognized and shared between by ITS-Ss can be increased significantly. Moreover, the accuracy of the estimated parameters (like object position, speed, etc.) increases with the number of ITS-Ss sharing information about the same object. In this case, receiving stations need to match and fuse information from multiple CPMs. Sensing ITS-Ss may also detect objects which are communicating ITS-S themselves (e.g. objects sending CA messages and alike).

Actors	Non-connected road users: • Vehicles. • Cyclists. • Pedestrians. • Etc. Are detected by: • Vehicles ITS-S equipped with sensors. • Roadside ITS-S equipped with sensors. CP messages are received by ITS-Ss (with or without sensors): • Vehicles. • Drivers. • Cyclists. • Pedestrians. • ITS central systems. • Etc.
Infrastructure Roles	A roadside ITS-S equipped with stationary sensors obtains object information from mounted stationary sensors and broadcasts detected objects via the CP message to surrounding ITS-Ss. The roadside ITS-S receives CP messages and forwards the CP messages to other ITS-Ss or aggregates the information of all received messages in a new CP Message.
Vehicle Roles	• ITS-Ss that are equipped with sensors transmit and receive CP messages. • ITS-Ss without sensors receive CP messages.
ITS Central System Roles	The central ITS-S at an ITS central system may receive CP messages and transmits these via the CP service to other vehicle, personal, or roadside ITS-Ss. The ITS central system is informed about non-connected road users via the CP service.
Other Traffic Participant Roles	-
Goal	• To detect all non-connected road users and transmit this information to all surrounding ITS stations. • To increase the accuracy of any road user information.
Needs	To include non-connected road users into safety applications.
Constraints/Presumptions	At least one ITS-S equipped with sensors.
Geographic Scope	Applicable to any road situation.
Pre-Conditions	• Vehicle or road side ITS-S equipped with sensors. • Non-connected road user. • V2X communication among ITS-Ss.
Main Event Flow	Sensor based object information about non-connected road users is sent by ITS-Ss to other ITS-Ss including central ITS-Ss.
Alternative Event Flow	-
Post Conditions	ITS-Ss are informed about non-connected road users.
Information Requirements	• Sensor information (position, speed, heading, dimensions, classification, etc.). • Host vehicle information (position, speed, heading, etc.).

4.1.3 Detection of Safety-Critical Objects

Use Case Name	Detection of Safety-Critical Objects.
Category	Safety.
Short Description	Apart from road users which are not able to communicate, there may be undesirable objects on the street or its vicinity representing a potential safety risk for road users. For example, these objects might be lost cargo, a tree limb or debris located on or close to the lane of a street. Sharing information about safety-critical objects enables safety applications warning approaching ITS-Ss about the presence of these safety-critical objects on the road. Furthermore, road users which are not equipped with sensors or whose sensors are not able to detect these safety-critical objects at all, are enabled to gain awareness of these safety-critical objects.

Actors	Non-connected safety critical objects: • Obstacles on the lane (tree limb, dustbin, barrier, debris, etc.). • Objects next to the lane with the ability to be moved (dustbin, skateboard, etc.). • Non-connected road users. ITS-Ss equipped with sensors: • Vehicle ITS-Ss. • Roadside ITS-Ss. ITS-Ss without sensor equipment: • Vehicles. • Cyclists. • Pedestrians. • ITS central systems. • Etc.
Infrastructure Roles	The roadside ITS-S that is equipped with stationary sensors obtains object information from stationary sensors and transmits it via CP service to ITS-Ss. The roadside ITS-S receives CP messages and forwards CP messages to other ITS-Ss or aggregates the information from received messages in a new CP Message.
Vehicle Roles	• Vehicle ITS-Ss equipped with sensors transmit and receive CP messages. • Vehicle ITS-Ss without sensors receive CP messages.
Central ITS System Roles	The central ITS-S of an ITS central system receives CP messages and transmits it via CP service to other vehicle, personal, or roadside ITS-Ss. The ITS central system is informed about safety critical objects via CP service.
Other Traffic Participant Roles	-
Goal	• To inform other road users and the ITS central systems about safety critical objects on or next to road areas. • To increase object detection/classification results.
Needs	To include safety critical objects into safety applications.
Constraints/Presumptions	At least one ITS-S equipped with sensors.
Geographic Scope	Applicable to any road situation.
Pre-Conditions	• Vehicle or roadside ITS-Ss equipped with sensors. • Safety critical object on or next to the road. • V2X communication among ITS-Ss.
Main Event Flow	Sensor based object information about safety critical objects on or next to the lane is sent by ITS-Ss to other ITS-S potentially including central ITS-Ss.
Alternative Event Flow	-
Post Conditions	ITS-Ss are informed about safety critical objects on or next to the lane.
Information Requirements	• Sensor information (position, speed, heading, dimensions, classification, etc.). • Host vehicle information (position, speed, heading, etc.).

4.1.4 CAM Information Aggregation

4.1.4.1 Introduction

In some situations, it can be meaningful to not only use sensor data but to also include information obtained from received CAMs to generate and send out a CP message. Applications using aggregated CAM information are typically relevant for services provided by the infrastructure side and the ITS central systems. Note that for security reasons it is necessary to authorize each ITS-S from which a CAM has been received. The following use-cases describe scenarios, where CAM information aggregation is meaningful.

4.1.4.2 Increasing Awareness

Use Case Name	Increasing Awareness
Category	Safety
Short Description	An intersection is a typical situation where an increased awareness range can be beneficial for safety purposes. Especially in situations with large number of ITS stations present, the observed channel load increases and the awareness range might be reduced. For such intersections, a roadside ITS-S may provide the CP service to the road users by periodically sending out CP messages. The roadside ITS-S might be equipped with stationary sensors to obtain information about objects. The roadside ITS-S might include information aggregated from received CAMs as well. As a result, traffic participants approaching an intersection from opposite directions can be recognized earlier. This is similar to the hidden node problem, where the first and the last transmitter in a row of three cannot hear each other. This application is not only relevant at local intersections as it may be applied for multiple consecutive intersections as well. An ITS central system receiving CPMs and CAMs may aggregate the received information and forward it to other ITS-Ss for increasing awareness about the traffic environment beyond the range of the local sensor and the short-range V2X communication.
Actors	• Vehicle ITS-Ss that can communicate with roadside ITS-Ss and or Central ITS-Ss. • Roadside ITS-Ss. • Central ITS-Ss.
Infrastructure Roles	The Roadside ITS-S receives CAMs from ITS-Ss and transmit the aggregated information via CPM to ITS-Ss potentially including the central ITS-Ss.
Vehicle Roles	Vehicular ITS-Ss transmit CAMs and/or receive CPMs.
Central ITS System Roles	The central ITS-S receives CAMs from ITS-Ss and transmit the aggregated information via CPM to ITS-Ss.
Other Traffic Participant Roles	-
Goal	To inform ITS-Ss or ITS central systems which are not within the range of local sensor or due to short-range V2X communication of other ITS-Ss in the proximity area.
Needs	To increase the awareness about other road users, especially with respect to the awareness range.
Constraints/Presumptions	The CAMs transmitted by ITS-S need to be receivable and decodable by other ITS-S, including roadside ITS-Ss and central ITS-Ss.
Geographic Scope	It applies especially to intersection and safety critical Sections of rural roads.
Pre-Conditions	Communication to roadside ITS-Ss and/or central ITS stations.
Main Event Flow	CAMs are transmitted from ITS-Ss and received by roadside and central ITS-Ss. Roadside and central ITS-Ss transmit the aggregated information via CPM to other ITS-Ss, which are relevant but are not able to receive the CAMs in the first place.
Alternative Event Flow	-
Post Conditions	ITS-Ss are informed about other ITS-Ss, even though they are not within the sensor range or the direct range of short-range communication.
Information Requirements	Host vehicle information (position, speed, heading, etc.).

4.1.4.3 Awareness about ITS-communication enabled persons on the road

Use Case Name	Awareness about person ITS-Ss on the road.
Category	Safety.
Short Description	In this scenario, a personal ITS-S device is actively sending out messages about its presence on the road to actively create awareness without relying on the person being detected by the on-board sensors of approaching vehicles. The messages include its position, sender designation (type), speed or heading. The information can be sent directly to surrounding vehicles (Person-to-vehicle, P2V), to the infrastructure (Person-to-infrastructure, P2I), or to the network (Person-to-Network, P2N). Information received at the infrastructure or network side is either used for presence detection or to derive further actions (e.g. sending out a warning message to approaching vehicles). In this context, the CP message is used for relaying and aggregating received messages from personal ITS-S devices by a roadside ITS-S.
Actors	Pedestrians with special relevance and high risk profile such as road workers, police agents, emergency personnel, fire brigade, etc. Vehicles, drivers. ITS central systems, e.g. traffic managers.
Infrastructure Roles	The roadside ITS-S receives the messages from the personal ITS-S and relays them in aggregated form: • To vehicles (I2V). • To the ITS central systems, e.g. traffic management centre.
Vehicle Roles	Vehicles receive the information directly from pedestrians (P2V), via the roadside ITS-S (I2V), or via the central ITS station (N2V), and can warn the drivers and/or take appropriate actions.
ITS Central System Roles	The central ITS-S receives the messages from the Personal ITS-S and relays them in aggregated form: • To vehicles. • To roadside ITS stations.
Other Traffic Participant Roles	-
Goal	To inform vehicle drivers, and ITS central systems, e.g. traffic managers, about pedestrians with special relevance and high risk profiles.
Needs	The need to specifically address the safety of road workers is addressed.
Constraints/Presumptions	Workers need to be equipped with ITS stations.
Geographic Scope	It applies to road work zone or other zones with high concentration of workers, traffic personnel or similar.
Pre-Conditions	Personal ITS-Ss need to be activated.
Main Event Flow	The information is sent to the infrastructure (Person-to-infrastructure, P2I) and/or ITS central systems (Person-to-network, P2N), and from there to vehicles (I2V and/or N2V) and/or roadside infrastructure.
Alternative Event Flow	The information is sent to and can be received directly by vehicles (Person-to-vehicle, P2V).
Post Conditions	Drivers are informed about persons on the road with high risk profile.
Information Requirements	CAMs are P2V, P2I and P2N. CPMs are sent I2V or N2V.

4.2 Terminology for sharing object information

The present document makes use of terminology that is specific to the domain of sensor data fusion and object detection methodologies. The following terminology is used throughout the present document.

Raw sensor data refers to low-level data generated by a local perception sensor that is mounted to a vehicle or RSU. This data is specific to a sensor type (e.g. reflexions, time of flight, point clouds, camera image, etc.). In the context of environment perception, this data is usually analysed and subjected to sensor-specific analysis processes to detect and compute a mathematical representation for a detected object from the raw sensor data.

Simply broadcasting raw sensor data is not a viable solution, as this imposes very high requirements regarding data rates and transmission frequencies, especially with increasing number of sensors attached to vehicles or RSUs. Nevertheless, if the channel resource permits, the transmitting ITS-S may attach the raw data to the CPM in future releases.

In the following, it is assumed that sensors mounted to stations are providing raw sensor data as a result of their measurements which is used by a sensor specific low-level object fusion system to provide a list of objects as detected by the measurement of the sensor. The detection mechanisms and data processing capabilities are specific to a sensor.

Therefore, the definition and mathematical representation of an **object** can vary. This mathematical representation is called a **state space representation** and, depending on the sensor type, may comprise multiple dimensions (e.g. relative distance components of the feature to the sensor, speed of the feature, geometric dimensions, etc.).

A state space is generated for each detected object of a particular measurement. A **measurement** is performed cyclically, depending on the sensor type. After each measurement, the computed state space of each detected object is provided in an **object list** that is specific to the timestamp of the measurement.

It is the task of an object fusion system to maintain a list of objects that are currently perceived by an ITS-S. The object fusion mechanism performs prediction of each object to timestamps at which no measurement is available from sensors; associates objects from other potential sensors mounted to the station or received from other ITS-Ss with objects in the tracking list; and merges the prediction and an updated measurement for an object [i.39], [i.40]. Therefore, at each point in time, a data fusion mechanism is able to provide an updated object list based on consecutive measurements from (possibly) multiple sensors containing the state spaces for all tracked objects. V2X information (e.g. CAMs) from other vehicles may additionally be fused with locally perceived information. Other approaches additionally provide alternative representations of the processed sensor data, such as an occupancy grid.

It is also the task of the data fusion mechanism to perform housekeeping, i.e. adding state spaces to the list of objects currently perceived by an ITS-S in case a new object is detected by a sensor; updating objects that are already tracked by the data fusion system with new measurements that should be associated to an already tracked object; and removing objects from the list of tracked objects in case new measurements should not be associated to already tracked objects. Depending on the capabilities of the fusion system, objects can also be classified (e.g. some sensor systems may be able to classify a detected object as a particular road user, while others are merely able to provide a distance measurement to "something" within the perception range).

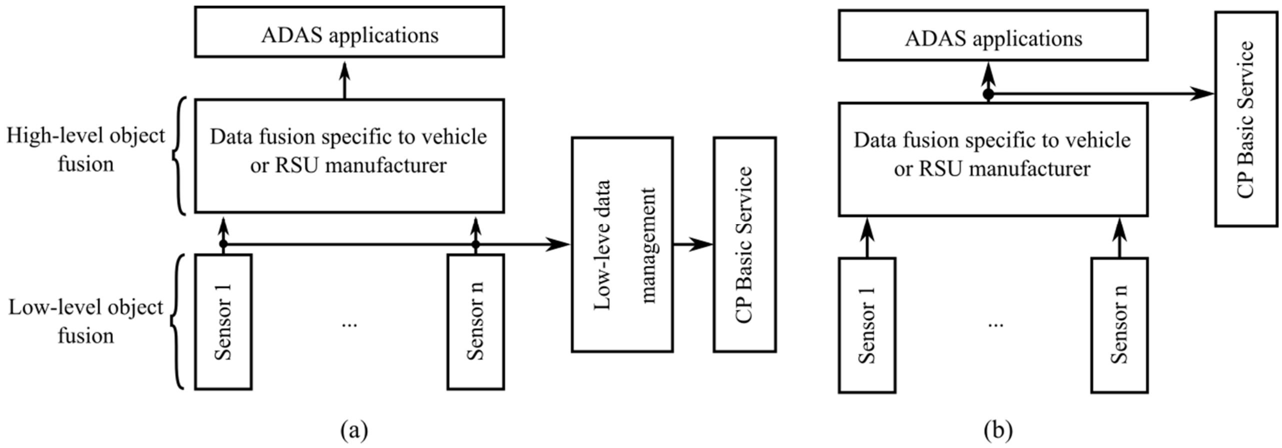


Figure 1: Object data extraction levels to be considered as part of the CP basic service

These tasks of object fusion may be performed either by an individual sensor, or by a high-level data fusion process.

The CP service enables sharing of object information from both regimes: Figure 1 (a) depicts an implementation in which sensor data is processed as part of a low-level data management entity. The CP Basic Service then selects the object candidates to be transmitted as defined in clause 4.3. Setup (a) is more likely to avoid filter cascades, as the task of high-level fusion will be performed by the receiving ITS-S.

Figure 1 (b) depicts an implementation in which the CP Basic Service selects objects to be transmitted as part of the CPM according to clause 4.3 from a high-level fused object list, thereby abstracting the original sensor measurement used in the fusion process. The CPM provides data fields to indicate the source of the object.

4.3 CPM Dissemination Concept

4.3.1 Introduction

Clause 4.3 specifies rules to generate CP messages. An example implementation can be found in annex D. Overall, a host-ITS-S should generate CPMs for surrounding objects it detected with sufficient level of confidence. If no objects are detected or selected for transmission, the ITS-S should still generate CPMs periodically to report that it is able to detect and share objects.

Hence, the proposed CPM generation method aims to balance frequent updates about detected objects and to minimize channel utilization: From the perspective of prospective applications consuming CPMs, the contained information should be as detailed as possible and updated information needs to be provided as often as possible. From the perspective of the employed communications stack, channel utilization should be reduced. This trade-off is studied in clause 5.

4.3.2 CPM Dissemination Considerations

4.3.2.1 CPM transmission

Point-to-multipoint communication, specified in ETSI EN 302 636-3 [i.43] may be used for transmitting CPMs.

4.3.2.2 Considerations for Modulation Schemes for CP Message Transmission

The Modulation and Coding Scheme (MCS) impacts the resulting channel usage. Increasing MCS (to e.g. QAM16 or higher) will effectively reduce the channel occupancy and can increase the channel capacity. In scenarios, where large packets are required (e.g. an infrastructure ITS-S sensing multiple objects), using higher MCS will increase the bandwidth efficiency and lower the channel congestion.

EXAMPLE: As a reference, QAM16 (rate ½) can support an effective range of more than 300 meters for ETSI Highway LOS channel models for both ITS-G5 and LTE-V2X. It should be noted that QAM16 may reduce the effective range as compared to QPSK (rate ½).

4.3.3 CP Service Activation and Termination

CP Service activation may vary for different types of ITS-S, e.g. vehicle ITS-S, road side ITS-S, personal ITS-S. As long as the CP Service is active, CPM generation should be managed by the CP Service.

For vehicle ITS-S, the CP service should be activated with the ITS-S activation. The CP service should be terminated when the ITS-S is deactivated.

4.3.4 CPM Generation Frequency Management

4.3.4.1 General considerations

A CPM generation event results in the generation of one CPM.

NOTE: The generated CPM may be segmented according to clause 4.3.6.

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* ≤ *T_GenCpm* ≤ *T_GenCpmMax*, where *T_GenCpmMin* = 100 ms and *T_GenCpmMax* = 1 000 ms.

In case of ITS-G5, *T_GenCpm* should be managed according to the channel usage requirements of Decentralized Congestion Control (DCC) as specified in ETSI TS 102 724 [i.14]. The parameter *T_GenCpm* should 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* should be set to *T_GenCpmMax* and if the value is below *T_GenCpmMin* or if this parameter is not provided, the *T_GenCpm* should be set to *T_GenCpmMin*. The parameter *T_GenCpm* represents the currently valid upper limit for the time elapsed between consecutive CPM generation events.

In case of LTE-V2X PC5, *T_GenCpm* should be managed in accordance to the congestion control mechanism defined by the access layer in ETSI TS 103 574 [i.15].

4.3.4.2 Perceived Object Container Inclusion Management

A CPM generated as part of a generation event may include information about perceived objects currently known to the transmitting ITS-S by adding a *PerceivedObject* DF to the *perceivedObjectContainer*.

An object from the object list of an ITS-S with sufficient confidence level and not subject to redundancy mitigation techniques (refer to clause 4.5) should be selected for transmission as a result of the current CPM generation event if the object complies to any of the following conditions:

1) If the assigned object class of highest confidence does not correspond to either the person or animal class:

   a) The object has first been detected by the perception system after the last CPM generation event.

   b) The Euclidian absolute distance between the current estimated position of the reference point of the object and the estimated position of the reference point of this object lastly included in a CPM exceeds 4 m.

   c) The difference between the current estimated absolute speed of the reference point of the object and the estimated absolute speed of the reference point of this object lastly included in a CPM exceeds 0,5 m/s.

   d) The difference between the orientation of the vector of the current estimated absolute velocity of the reference point of the object and the estimated orientation of the vector of the absolute velocity of the reference point of this object lastly included in a CPM exceeds 4 degrees.

   e) The time elapsed since the last time the object was included in a CPM exceeds *T_GenCpmMax*.

2) If the assigned object class of highest confidence corresponds to either the person or animal class:

   a) A new object (of class person or animal) is detected after the last CPM generation event.

   b) If the object list contains at least one object of class person or animal which has not been included in a CPM in the past 500 ms, all objects of class person or animal should be included in the currently generated CPM.

NOTE 1: The generation rules for objects of class person or animal ensure that there are no individual inclusion cycles for previously included objects of these two classes to reduce message generation frequency.

To further reduce the number of generated messages, at each message generation event, the objects not belonging to either the person or animal class to be included in a CPM in the next generation event (i.e. after *T_GenCpm)* can already be included in the currently generated CPM. For this purpose, objects that are not selected for transmission in the currently generated CP message are predicted to the next CP message generation event (i.e. after *T_GenCpm*), for example assuming a constant velocity model. Following this prediction, all objects that would then need to be included in a CPM in the next generation event should also be selected for inclusion in the currently generated CPM.

NOTE 2: The simulation studies presented in clause 5 provide insights regarding the benefits and drawbacks of the aforementioned mechanism.

4.3.4.3 Sensor Information Container Inclusion Management

A CPM generated as part of a generation event should include a *SensorInformationContainer* whenever the time elapsed since the last time a CPM included a *SensorInformationContainer* is equal or greater than *T_AddSensorInformation*, where *T_AddSensorInformation* = 1 000 ms.

4.3.4.4 Free Space Addendum Container Inclusion Management

Confirmed free space in a CPM can be indicated as part of the *SensorInformationContainer*. Clause 6.7 details how the combination of the free space indication (*FreeSpaceConfidence* DE in the *SensorInformationContainer*) and described objects can be combined to derive the free space by using a tracing and shadowing approach. The *FreeSpaceAddendumContainer* should be added whenever a free space area as would be computed on the receiver side using the simple tracing approach detailed in clauses 6.5 and 6.7 does not reflect the detected free space of the ITS-S generating the CPM.

In case of static information, such as a permanently shadowed region, the *FreeSpaceAddendumContainer* should be added whenever the *SensorInformationContainer* is added to the currently generated CPM.

A CPM generated as part of a generation event may include additional information about monitored free space areas known to the transmitting ITS-S by adding a *FreeSpaceAddendum* DF to the *freeSpaceAddendumContainer*.

A particular *FreeSpaceAddendum* should be added to the CPM if the simple tracing approach to compute free space areas on a receiving ITS-S does not match the representation of the detected free space on the transmitting ITS-S.

Consecutive inclusion of a *FreeSpaceAddendum* in the CPM is contingent to:

1) In case the particular *FreeSpaceAddendum* DF employs the *AreaPolygon* DF: A *FreeSpaceAddendum* should be added to the current CPM if the Eucledian relative distance of any *OffsetPoint* of the polygon relative to the corresponding *OffsetPoint* of this polygon lastly included in a CPM exceeds 4 m or if the number of *OffsetPoints* to describe the polygon changes.

2) In case the particular *FreeSpaceAddendum* DF employs the *AreaCircular* DF, *AreaEllipse* DF or *AreaRectangle* DF:

   a) A *FreeSpaceAddendum* should be added to the current CPM if the difference between the current Euclidian distance of the *NodeCenterPoint* of the described free space area and the Euclidian distance of the *NodeCenterPoint* of the same described free space area and lastly included in a CPM exceeds 4 m.

   b) A *FreeSpaceAddendum* should be added to the current CPM if the difference between the current *Radius* or *SemiRangeLength* of the described free space area and the *Radius* or *SemiRangeLength* of the same described free space area lastly included in a CPM exceeds 4 m.

   c) A *FreeSpaceAddendum* should be added to the current CPM if the difference between the current *semiMajorRangeOrientation* of the described free space area and the *semiMajorRangeOrientation* of the same described free space area lastly included in a CPM exceeds 4 degrees.

4.3.5 Considerations for Decentralized Congestion Control Mechanisms

A DCC algorithm may be used to limit access to the channel in congested scenarios. Thus the CPM generation rules may be impacted by access layer DCC. As a result, a CP message may be dropped by the access layer DCC. If this packet drop indication is fed back to the CPM generation function, this feedback can be used to re-consider adding the objects from the dropped packet to the pool of objects to be select for the next CP message generation event. The feedback mechanism can employ provisions from the cross-layer DCC functionality detailed in ETSI TS 103 175 [i.16].

4.3.6 CP Message Segmentation

The size of a generated CPM should not exceed MTU_CPM which the CP service supports via the NF-SAP, i.e., the MTU_CPM depends on the MTU of the access layer technology (MTU_AL) over which the CPM is transported.

MTU_CPM should be less than or equal to MTU_AL reduced by the header size of the facilities layer protocol (HD_CPM) and the header size of the networking and transport layer protocol (HD_NT) with MTU_CPM ≤ MTU_AL - HD_CPM - HD_NT.

The MTU_AL per access layer technology is defined in [i.10], [i.11], and their references. The header of the networking and transport layer protocol consists of the BTP header and the GeoNetworking header. The size of BTP header is defined in [i.12] and the size of GeoNetworking protocol header per intended packet transport type is defined in [i.13].

In case the size of the ASN.1 UPER encoded CPM including all perceived object candidates selected for transmission exceeds MTU_CPM, message segmentation should occur. Each message segment can be interpreted without the need to receive all segments. Selected perceived object candidates should be included in a CPM segment in a descending order of the product of an object's confidence (if available) and speed. In case the object confidence is unavailable (101), only the object speed should be used for sorting in a descending fashion. A segment should be populated with selected objects as long as the resulting ASN.1 UPER encoded message size of the segment to be generated does not exceed MTU_CPM. Segments are generated in this fashion until all selected perceived objects are included in a CPM segment. Each segment is transmitted at the next transmission opportunity.

In case the *SensorInformationContainer* also needs to be transmitted, it should be added to a CPM segment if the resulting ASN.1 UPER encoded CPM segment size does not exceed MTU_CPM.

NOTE: This procedure may result in the generation of a CPM segment only including the *SensorInformationContainer*.

Message segmentation should be indicated by populating the *perceivedObjectContainerSegmentInfo* DF. All message segments should indicate the same *generationDeltaTime* DE.

4.4 Quality and Confidence Indication of Provided Data

4.4.1 Object Inclusion and Confidence

Objects to be included in the CP message should be shared with other ITS-Ss with the objective of increasing traffic safety. Shared objects are therefore used by safety applications on receiving ITS-S. Objects relevant for traffic safety are either static, i.e. do not move but are located on the driving lanes, or dynamic, i.e. move or have the ability to move. The objective of transmitted objects as part of the CP Message is not to share and to compare traffic-regulation information such as traffic signs and traffic light information. Instead, data about objects which cannot be available to other ITS-Ss as their presence is only temporary (e.g. traffic participants or temporary obstacles) need to be given priority.

Objects need to be located on the driving lanes or adjacent to lanes (e.g. pedestrian walks). Map matching algorithms on the disseminating ITS-Ss may be used for determining whether an object is located on a lane.

The methodology to compute object confidence will be unanimous between transmitting ITS-S to ensure that upon reception of a CPM, the confidence indication can be clearly interpreted. In sensor fusion systems, confidence computation is usually proprietary to the implementation and therefore contradicts the requirements when sharing sensor data. Therefore, suitable confidence metrics should be identified (e.g. in ISO/AUTOSAR), to provide a harmonized description.

4.4.2 Free Space Confidence

Receivers are able to combine the reported detection area of the *SensorInformationContainer* and the reported objects to derive free space between the objects, as detailed in clauses 6.5 and 6.7. To advertise that the transmitting ITS-S is able to provide measurements about actual confirmed empty space that a receiving moving ITS-S may drive into, the optional *freeSpaceConfidence* DE of a particular *SensorInformation* should be used.

A semantic segmentation process is a key step in identifying objects and free space within the field of view of a sensor [i.18], [i.19]. Depending on the employed sensor measurement and object fusion principles, detected objects can be described with bounding boxes of fixed size. By combining the knowledge about the transmitting ITS-S's sensory capabilities, i.e. its detection area, with received detected objects, free space can be can be computed by a receiving ITS-S. When objects and free space are classified, applicable confidence levels should be determined by using an applicable methodology (e.g. Artificial intelligence technique [i.20]).

The confidence level of a free space can be defined as the ratio of the number of detected evidences of free space with respect to the total number of detection attempts within a specified time period such as *T_GenCpmMax*. The specific technique for sematic segmentation, multi sensor data fusion, and confidence level calculations for object/free space are out of scope for the present document and any feasible technique should be used.

4.5 Redundancy Mitigation Techniques

4.5.1 General Considerations

In case of multiple ITS-Ss perceiving the same (physical) object, redundant and unnecessary frequent updates about that object will be broadcast, thereby increasing the network channel load. The high channel load may lead to frequent losses of CPMs, which may in turn degrade performance of the CP service. In order to reduce the message size, the CP Service may optionally omit a subset of the perceived objects that meet pre-defined redundancy mitigation rules.

In general, means of reducing redundancy in the context of Collective Perception are associated with the following benefits and drawbacks:

- General benefits of redundancy mitigation techniques:
  - Reduced channel utilization, leading to higher likelihood for more relevant information to be propagated successfully.
  - Smaller message size as fewer objects will be transmitted per message.

- General drawbacks of redundancy mitigation techniques:
    - A transmitting ITS-S may not be aware of receivers that require object information and may incorrectly omit an object from the CPM, even if only this transmitting ITS-S should provide information about that object to a particular receiving ITS-S (i.e., the transmitting ITS-S may not know that this particular receiving ITS-S does not receive CPMs from other surrounding ITS-Ss also transmitting a CPM).
    - Most approaches assume that data association between locally perceived objects and those received via CPMs is correct. Erroneous object information or incorrectly omitted object information can degrade performance of the CP service.
    - Minimum data quality cannot be ensured, especially if a particular redundancy mitigation technique further delays object information propagation and therefore increases the data age on receiving ITS-Ss.
    - Redundancy mitigation techniques may be prone to the loss of CPMs due to radio propagation or interference effects, as locally perceived objects may be omitted from the new CPM even if any remote ITS-S has failed to receive a particular historical CPM that includes the object information.
    - Redundancy mitigation techniques assume that other surrounding ITS-Ss perform the same or a similar redundancy mitigation technique, which may not always be the case. Especially in mixed traffic scenarios, in which only a subset of communicating vehicles is able to both receive and transmit CPMs, it cannot be assumed that surrounding stations will be capable of CPM reception.

A transmitting ITS-S should enable the redundancy mitigation technique only when the observed network channel load (e.g. channel busy ratio) is higher than a threshold *L_Redundancy*. Otherwise, a CPM may include all the locally perceived objects that are selected by the CP message generation rules in clause 4.3.

There are several possibilities to realize redundancy mitigation techniques. The following sections represent a non-complete list and description of possible approaches for redundancy mitigation techniques.

4.5.2 Frequency-based Redundancy Mitigation Rule

On each CPM generation event, the transmitting ITS-S analyses a history of CPMs that it has received from remote ITS-Ss during the recent time window of length *W_Redundancy*. The frequency-based redundancy mitigation rule omits locally perceived objects from the new CPM if the number of historical CPMs that include information about the same objects is more than a threshold *N_Redundancy*.

NOTE: An historical CPM may be considered to include information about the same object only if the transmitting ITS-S can associate the object information in the historical CPM with the locally perceived object with a confidence higher than a threshold *C_Redundancy*.

Benefits of the frequency-based redundancy mitigation rule in addition to the general benefits listed above:

- The impact of the potential loss of CPMs can be mitigated by increasing the threshold *N_Redundancy*, as this will correspond to an increase of the likelihood that each remote ITS-S can receive at least one of the previous CPMs that include information about the same object during the time window of length *W_Redundancy*.

Drawbacks of the frequency-based redundancy mitigation rule in addition to the general drawbacks listed above:

- A higher value for the threshold *N_Redundancy* results in information about the same object being transmitted more frequently, thereby limiting the reduction of network channel load.
- A locally perceived object may be omitted from a new CPM regardless of the quality of object information included in any previous CPM. If any of the previous CPMs contain only inaccurate information about the locally perceived object, omitting that object information from a new CPM may lead to a performance degradation of the CP service on the receiver side.
- The information about a locally perceived object should be transmitted in a burst of *N_redundancy* CPMs. After this burst, no CPM would include information about that object during the remainder of the time window *W_Redundancy*. This might not be optimal for object tracking systems.

4.5.3 Dynamics-based Redundancy Mitigation Rule

On each CPM generation event, the transmitting ITS-S analyses the last CPM that it has received from all remote ITS-Ss. The dynamics-based redundancy mitigation rule omits a perceived object if:

- The Euclidian absolute distance between the current estimated position of the reference point of the object and the estimated position of the reference point of this object lastly included in a received CPM is below *P_Redundancy*, with *P_Redundancy* ≤ 4 m.
- The difference between the current estimated absolute speed of the reference point of the object and the estimated absolute speed of the reference point of this object lastly included in a received CPM is below *S_Redundancy*, with *S_Redundancy* ≤ 0,5 m/s.

NOTE: An historical CPM may be considered to include information of the perceived object only if the transmitting ITS-S can associate the received object information with the perceived object with a confidence higher than a threshold *C_Redundancy*.

Benefits of the dynamics-based redundancy mitigation rule in addition to the general benefits listed above:

- A locally perceived object moving at a higher speed or with a higher acceleration will be reported more frequently than a locally perceived object moving at a lower speed or with a lower acceleration.
- If the speed of a locally perceived object is constant, it will be reported periodically, i.e. with regular time intervals, which can benefit object tracking systems.
- With *P_Redundancy* = 4 m and *S_Redundancy* = 0,5 m/s, the redundancy as a result of multiple transmissions can be reduced. Multiple transmitters perceiving the same object generate a reporting rate similar to that of a single transmitter.

Drawbacks of the dynamics-based redundancy mitigation rule in addition to the general drawbacks listed above:

- A lower *P_Redundancy* and *S_Redundancy* result in information about the same object being transmitted more frequently, thereby limiting the reduction of network channel load.

4.5.4 Confidence-based Redundancy Mitigation Rule

On each CPM generation event, the transmitting ITS-S analyses a history of CPMs that it has received from remote ITS-Ss during the recent time window of length *W_Redundancy*. The confidence-based redundancy mitigation rule omits locally perceived objects from the new CPM if:

i) any of the historical CPMs includes information about the same objects; and

ii) the maximum confidence of the object information in these historical CPMs is higher than the confidence of the transmitting station's local perception of this object.

Benefits of the confidence-based redundancy mitigation rule in addition to the general benefits listed above:

- The object information with higher confidence can be prioritized under heavy network channel load.

Drawbacks of the confidence-based redundancy mitigation rule in addition to the general drawbacks listed above:

- This rule may be prone to the loss of CPMs due to radio propagation or interference effects, as a locally perceived object may be omitted from the new CPM even if some remote ITS-Ss have failed to receive a particular previous CPM that includes the object information with the highest confidence ("hidden" station).

4.5.5 Entropy-based Redundancy Mitigation Rule

On each CPM generation event, the transmitting ITS-S identifies a set of neighbouring ITS-Ss whose distance from the transmitting ITS-S is within a threshold *D_Redundancy*. The threshold *D_Redundancy* should be set to less than or equal to a typical communication range of ITS-Ss. The basic idea of the entropy-based redundancy mitigation rule is to have the transmitting ITS-S anticipate the neighbouring ITS-Ss' prior knowledge about the current state (e.g. ground position, ground speed, etc.) of each locally perceived object, and exclude the object from the new CPM if all the neighbouring ITS-Ss are expected to already track the accurate object state [i.41].

The transmitting ITS-S first anticipates a set of historical CPMs that each of these neighbouring ITS-Ss received during the recent time window of length *W_Redundancy*. The transmitting ITS-S may introduce a conservative assumption that each neighbouring ITS-S received only a subset of historical CPMs that the transmitting ITS-S received during the same time window. Whether or not a CPM was received by a neighbouring ITS-S can be estimated based on the distance between the neighbouring ITS-S and the ITS-S which sent that historical CPM.

Let $K_{pri}(\boldsymbol{x})$ denote the anticipated prior knowledge of a neighbouring ITS-S about the state $\boldsymbol{x}$ of a locally perceived object, which is represented as a probability density function. The function $K_{pri}(\boldsymbol{x})$ is estimated by the transmitting ITS-S by means of applying a data fusion algorithm (e.g. Kalman filter) to the series of historical CPMs that the neighbouring ITS-S is expected to have received. Likewise, let $K_{pos}(\boldsymbol{x})$ denote anticipated posterior knowledge of the neighbouring ITS-S about the object state in the case that the transmitting ITS-S decides to include that locally perceived object into its new CPM. The function $K_{pos}(\boldsymbol{x})$ is estimated in the same way as $K_{pri}(\boldsymbol{x})$ except that the latest object information perceived by the transmitting ITS-S is used as an additional input to the data fusion algorithm. Based on the anticipated knowledge of the neighbouring ITS-S, the transmitting ITS-S calculates the *relative entropy* ν of the locally perceived object information:

$$\nu = \int_{-\infty}^{\infty} K_{pos}(\boldsymbol{x}) \ \log \frac{K_{pos}(\boldsymbol{x})}{K_{pri}(\boldsymbol{x})} d\boldsymbol{x}.$$

The relative entropy indicates the information gain between the prior and posterior knowledge, and thereby signifies the novelty of the locally perceived object information for that neighbouring ITS-S.

In the entropy-based redundancy mitigation rule, an object perceived by the transmitting ITS-S may be excluded from the new CPM if the object meets both of the following conditions:

a) All the neighbouring ITS-Ss are expected to perceive this object.

b) For all the neighbouring ITS-Ss, the relative entropy of that locally perceived object information is lower than a threshold *E_Redundancy*.

Benefits of the entropy-based redundancy mitigation rule in addition to the general benefits listed above:

- This rule can mitigate the impact of the potential loss of CPMs by taking into account the distance between ITS-Ss when estimating a set of historical CPMs that each neighbouring ITS-S is expected to have received.
- It considers quality and freshness of the object information in calculating the anticipated knowledge of neighbouring ITS-Ss. It helps mitigate the risk of incorrectly omitting object information from CPMs.

Drawbacks of the entropy-based redundancy mitigation rule in addition to the general drawbacks listed above:

- A transmitting ITS-S needs to anticipate knowledge about each locally perceived object from each neighbouring ITS-S's perspective, which leads to additional computational overhead.
- The anticipated knowledge may be inaccurate if a neighbouring ITS-S's data fusion algorithm and metric for expressing "knowledge" is different from the transmitting ITS-S's algorithm.

4.5.6 Object Self-Announcement Redundancy Mitigation Rule

Objects detected by local perception sensors, such as other vehicles or other traffic participants, may themselves also be ITS-Ss, i.e. be able to transmit and receive V2X messages such as the CAM or the CPM. In case a transmitting ITS-S is capable of matching received V2X messages to objects detected by local perception sensors, it may be assumed that other receiving ITS-Ss also received the V2X message from this object. Consequently, a locally detected object which is also capable of transmitting V2X messages itself may be omitted from a newly generated CPM.

Benefits of the object self-announcement redundancy mitigation rule in addition to the general benefits listed above:

- Resulting CP message size decreases with increasing market penetration rate, as other ITS-S are no longer included in a CPM.

Drawbacks of the object self-announcement redundancy mitigation rule in addition to the general drawbacks listed above:

- It is assumed that all other surrounding ITS-S also receive the V2X message from the object omitted from the CPM which may not always be the case in challenging signal propagation environments.

- It is assumed that the transmitter omitting the particular object to which it matched a received V2X message is correctly associating the received V2X message with the measurement of the local perception sensor. This association may be associated to errors, in which case a detected object is omitted from a message erroneously.

4.5.7 Distance-based Redundancy Mitigation Rule

On each CPM generation event, the transmitting ITS-S analyses a history of CPMs that it has received from remote ITS-Ss. The distance-based redundancy mitigation rule omits redundant objects among locally perceived objects from the new CPM:

- if the same objects are included in the received CPMs from remote ITS-Ss during the recent time window of length *W_Redundancy*; and
- if any of the Euclidian absolute distances between the current reference point of the transmitting ITS-S and the reference points of the remote ITS-Ss, i.e. the remote ITS-Ss' reference points which are indicated in lastly received CPMs including the same objects, is less than a threshold range of *R_Redundancy*.

Benefits of the distance-based redundancy mitigation rule in addition to the general benefits listed above:

- The awareness range will be efficiently increased. The perceived object information can be propagated farther with limited amount of redundancy.
- The network channel load will be reduced by limiting redundancy when it does not effectively increase the awareness range.

Drawbacks of the distance-based redundancy mitigation rule in addition to the general drawbacks listed above:

- An appropriate value of the threshold range, *R_Redundancy* should be found. If it is too small, the network channel load will not be properly reduced. If it is too large, the benefit of the increase awareness range will not be achieved even though the network channel load can be reduced well.

In addition, the distance-based redundancy mitigation rule can be applied to CAM information aggregation described in clause 4.1.4. On each CPM generation event, the transmitting ITS-S analyses a history of CAMs that it has received from remote ITS-Ss. The distance-based redundancy mitigation rule omits locally perceived objects from the new CPM:

- if the perceived object is one of the remote ITS-Ss sending the CAMs which are received by the transmitting ITS-S during the recent time window of length *W_Redundancy*; and
- if the Euclidian absolute distances between the current reference point of the transmitting ITS-S and the reference point of the perceived object, i.e. the remote ITS-S's reference point which is indicated in the lastly received CAM or the perceived reference point of the object, is less than a threshold range of *R_Redundancy*.

5 Simulation Study

5.1 Introduction

To maximize the effectiveness of the Collective Perception Service, it is crucial to get a deeper understanding of how its mechanisms such as the generation rules and message composition operates in different situations. Only then, meaningful parametrizations can be found and mechanisms can potentially evolve. Thus, two simulation studies were performed, assessing different aspects of the CP Service by measuring core-metrics, such as the channel load and the generated awareness. This is especially important when the CPM is sent in the same radio channel as other ITS messages, such as the CAM. Preliminary work has been conducted in [i.3].

To get an overview, diverse scenarios have been simulated, each focusing on specific evaluation aspects of the CP Service. Additional metrics specific to the generation rules are assessed as well. Clause 5 discusses these studies and their results.

5.2 Research Domains

5.2.1 Introduction

The research questions addressed by these simulation studies are grouped into the categories specified in clauses 5.2.2, 5.2.3 and 5.2.4.

5.2.2 Assessment of Different Message Generation Rules

- What is the message generation rate and size?
- What is the effect of different message generation rules on the resulting channel load?
- What is the effect of these message generation rules on the generated awareness?

5.2.3 Variation of DCC Parameters and Radio Configurations

- What is the influence of different DCC profiles for the CPM on other ITS messages on the same channel?
- What is the effect of DCC operations on CPM transmissions?

5.2.4 Message Segmentation

- Is there a need for message segmentation?

5.3 Simulation Environments

5.3.1 Introduction

Two separate simulation studies were performed by two contributing parties as part of the analysis. Clause 5.3 introduces the respective simulation setups and settings. In the clauses below, results from the first study are labelled with "S1", results from the second study are labelled with "S2".

5.3.2 Simulation Framework of Study S1

5.3.2.1 Introduction

The first study employs the simulation framework Artery [i.21]. Artery is available as free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use. Artery couples the dedicated network simulator OMNeT++/OMNEST [i.22] with the traffic simulator Simulation of Urban MObility (SUMO) [i.24]. It includes a complete ETSI ITS-G5 stack and realistic models for signal propagation and shadowing which are provided by the INET framework [i.23].

As part of this study, an implementation of the CP Service was developed, that concurs to the description in the present document. The CP Service generates CPMs according to the ASN.1 encoding given in annex A. The CP Service leverages Artery's local environment model to gain information about objects in the vicinity of the host vehicle and includes those as Perceived Objects in the CPM. The interconnection between these components is shown in Figure 2. The microscopic traffic simulator represents the virtual driving environment of the vehicles, providing realistic road geometries and motion profiles of the vehicles within the network simulator. The latter instantiates a complete ETSI ITS G5 conformant communication stack for each communication enabled vehicle. Each vehicle is therefore associated to its own CP and CA service with individual message triggering frequencies. More details about the integration of the CP Service into Artery can be found in [i.25].

5.3.2.2 Local Perception Sensors

Artery comes with an environment model that also includes radar sensors. These were used as local perception sensors to acquire information about neighbouring objects that potentially need to be included in the CPM. The sensors detect all objects that are not shadowed by buildings or other vehicles using a simple ray-tracing like approach. Sensor noise or other inaccuracies are not modelled in Artery. More details about the implementation of sensors in Artery can be found in [i.28].

Two different radar configurations were implemented for this study, as shown in Figure 3. The first employed sensor is a realistically parameterized, combined mid and long range radar. The second sensor employs an artificial setup with a field-of-view of 360° to be able to generate large CP messages in specific scenarios.

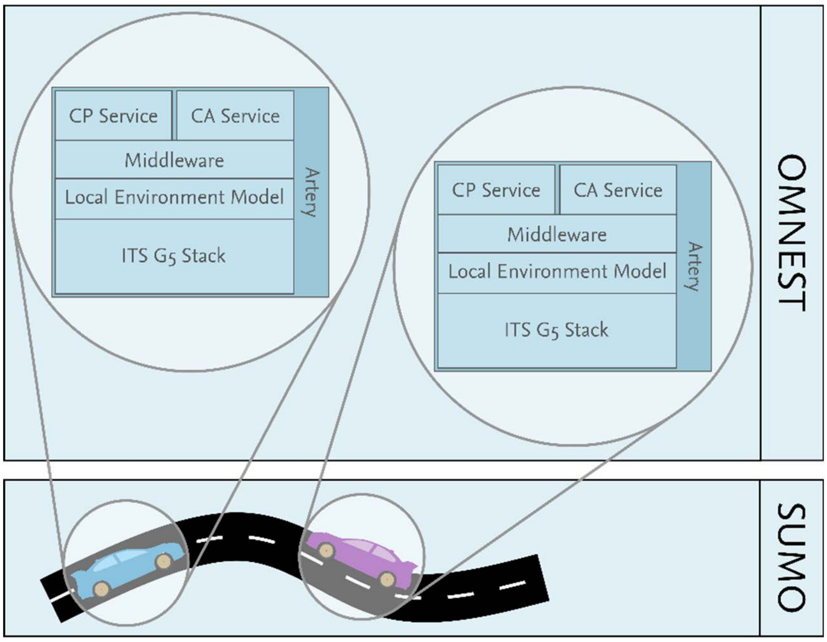


Figure 2: Architecture of the Artery Simulation Framework

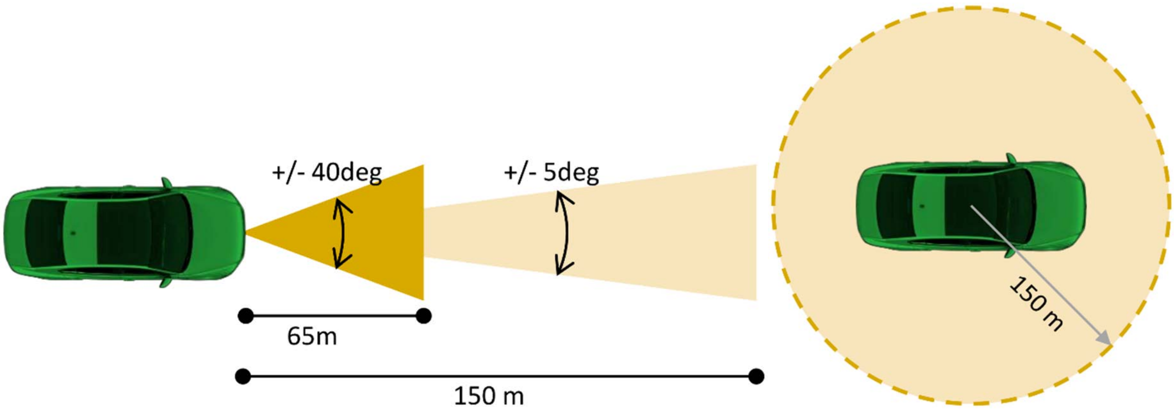


Figure 3: The two implemented radar configurations

5.3.2.3 Scenarios

5.3.2.3.1 Introduction

To gather information about the CP Service's performance in realistic traffic scenarios and different traffic situations, two different scenarios are employed by the simulations. These two scenarios are described in clauses 5.3.2.3.2 and 5.3.2.3.3.

5.3.2.3.2 Luxemburg Scenario

This first scenario is the Luxemburg SUMO Traffic scenario [i.27], as depicted in Figure 4. It features 24 h of traffic demand in the state of Luxemburg and is well-established in research for realistic simulations of vehicular traffic. The scenario is very diverse and includes a plethora of different traffic situations in urban and sub-urban areas as well as on highways. As depicted, the scenario also includes obstacles (red areas in Figure 4) representing buildings and other obstacles alongside the road geometry which are considered by Artery's vehicle sensors. In conjunction with the local perception sensors mounted to the vehicle, these obstacles might shadow other vehicles within a sensor range, resulting in a more realistic perception profile for each vehicle [i.28]. It should be noted that the employed communication model does not account for obstacle shadowing to increase the number of vehicles in communication range and therefore slightly overestimates the observed channel load compared to real traffic scenarios.

Figure 5 depicts the varying traffic demand in the scenario. There are three main rush-hour scenarios at around 08:00 h, 14:00 h and 18:00 h. The maximum number of vehicles simultaneously in the simulation was around 4 700 at 08:00h.

For the simulations, a timeslot of five seconds every two hours throughout the day was evaluated, resulting in a total number of eleven slots.

Figure 4: Overview of the Luxemburg scenario with locations of static probes

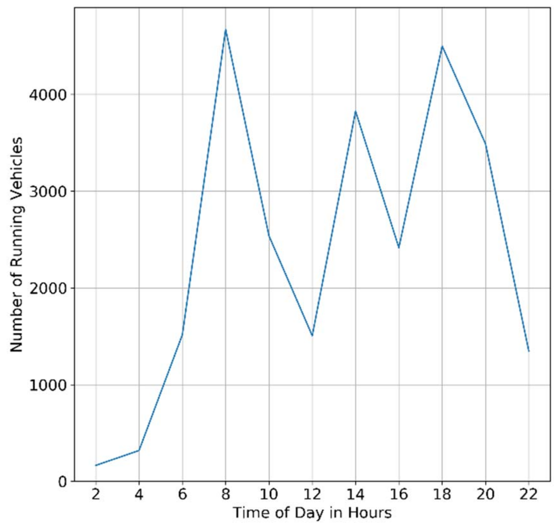
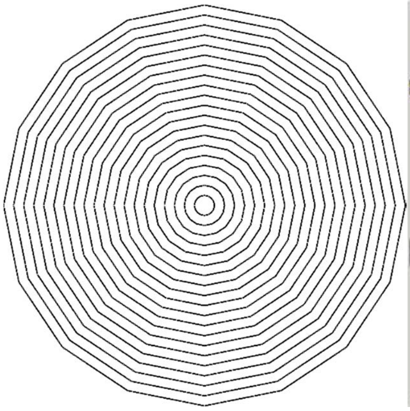


Figure 5: Number of running vehicles over the day

5.3.2.3.3 Spider Scenario

Next to the aforementioned realistic traffic scenario, another scenario was specifically created to evaluate the CP Service in situations of challenging channel loads. It is comprised of 20 concentric rings with an inter-ring distance of 50 m and no obstacles between them (see Figure 6). The name "Spider"-scenario is thereby derived from its appearance and is used as a reference to this scenario in clause 5.4. Each ring consists of two opposing lanes with vehicles driving at a high constant speed 140 km/h. Every CP Service enabled vehicle is equipped with the aforementioned 360° radar sensor, therefore being able to generate very large CP messages.

The missing buildings do not only result in unblocked radar view but also unhindered radio transmission. Therefore, all the messages sent, i.e. CAMs and CPMs, are received by almost every other vehicle. Those effects combined assure maximum possible channel load and heavy DCC operation.



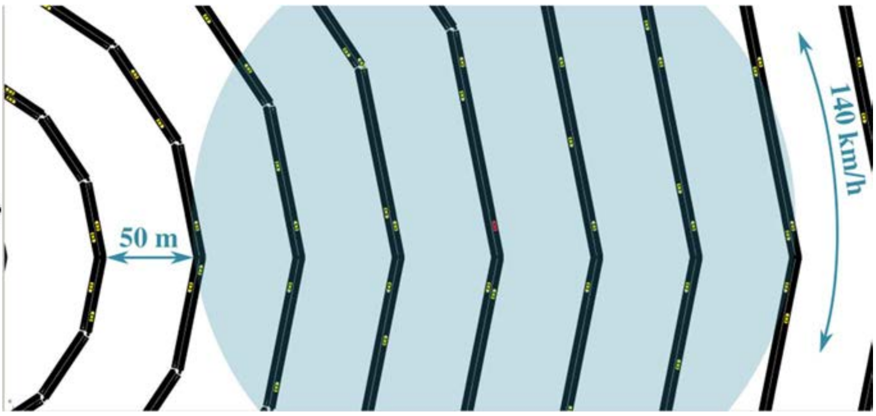


Figure 6: The Spider scenario as overview (left) and in detail (right)

5.3.2.4 Parameterization of Simulation Study S1

To assess the operations of the CP Service in different circumstances, multiple simulations have been performed. Table 1 details the configuration of the fixed parameters of the simulations.

Table 2 details the varied simulation parameters. Two different traffic scenarios, as detailed in clauses 5.3.2.3.2 and 5.3.2.3.3 were employed. Six different market penetration rates for V2X communication enabled vehicles, varying from 5 % to 100 %, have been selected for the simulations. Every communication enabled vehicle is thereby able to transmit both CPM and CAM. To compare the performance of the proposed message generation rules detailed in clause 4.3 (dynamic generation rules) to a high-load generating baseline configuration, an additional *static* generation rule variant has been simulated. This configuration triggers the transmission of complete message (see clause 6.1) with every container every 1 s and includes objects known to the disseminating ITS-S every 100 ms. This setup is particularly important in combination with the Spider scenario as due to the highly dynamic network nodes, it is expected that the proposed dynamic generation rules outlined in clause 4.3 trigger every time for every object, leading to large CP Message sizes, generated at the maximum rate of 10 Hz and hence result in the same performance as the static rules. These parameter variations are combined with three different possible radio configurations. The first configuration transmits both CAMs and CPMs on the CCH with a DCC Priority of DP 2. The second configuration transmits both messages on the control channel with a lower priority of DP3 for the CPM, whereas the third configuration provides multi-channel capabilities by transmitting the CAM on the CCH and the CPM on the SCH1. These configurations are employed to assess the effect of the CP service on the resulting channel utilization.

CP Messages transmitted in these simulations make use of all mandatory data fields, with additional optional data fields employed for the Station Data and Perceived Object Container to reflect more realistic utilization of data fields as expected when vehicles transmit CPMs. The *vehicleOrientationAngle, longitudinalAcceleration, lateralAcceleration* and *yawRate* DFs have been added as optional DFs for the Station Data Container, resulting in a total size of about 16 bytes to describe the originating vehicle state. The optional *sensorID, objectAge, objectConfidence, yawAngle, planarObjectDimension1, planarObjectDimension2, dynamicStatus* and *classification* DFs have been added for the Perceived Object Container, resulting in an average size of about 31 bytes for each object included in the message.

The full-factorial design results in a total of 432 simulation runs with up to 4 700 participating vehicles per run.

Table 1: Fixed Simulation Parameters

Parameter	Configuration
Data Bitrate	6 Mbit/s
Transmission Power	200 mW (23 dBm)
Radio Propagation Model	Two Ray Interference Model [i.23]
Maximum Interference Range	1 500 m
DCC Finite State Machine	TRC, 3x Active, 500 µs T_{on} [i.26]
DCC Queue Length	2

Table 2: Variable Simulation Parameters

Parameter	Variations
Traffic Scenario	Luxemburg, Spider
Market Penetration Rate in percent	5, 10, 25, 50, 75, 100
CPM Generation Rules	• *Static*: Complete message every 1 s (all containers), Minimum message every 100 ms (all containers except for Sensor Information Container • *Dynamic*: Proposed Generation rules (see clause 4.3)
Radio Configuration	• Single Channel (CCH), CAM & CPM as DP2 • Single Channel (CCH), CAM (DP2), CPM (DP3) • Multi Channel (CAM on CCH, CPM on SCH1, both DP2)

5.3.3 Simulation Framework of Study S2

5.3.3.1 Introduction

The second study employs the ns3 network simulator [i.29] and SUMO [i.24]. ns-3 is a discrete-event network simulator, targeted primarily for research and educational use. ns-3 is available as free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use. In this study, the ns3 version extended for V2X communications in the iTETRIS platform has been used [i.30]. Part of the results presented in the present document were published in [i.31] with extensions published in [i.32] and [i.42].

To conduct this study, ns3 has been extended with a CP Service and different local perception sensors. The local perception sensors are used by each vehicle to determine the list of Perceived Objects at an interval of *T_GenCpm*. This list is used to generate CPMs following different generation policies. The CPM generation rules defined in clause 4.3 have been implemented and evaluated with the *T_GenCpm* parameter set to 100 ms, so that the maximum CPM rate is 10 Hz. In addition, two different periodic policies with 10 Hz (*T_GenCpm* = 0,1 s) and 2 Hz (*T_GenCpm* = 0,5 s) have been considered as a baseline with each CPM including all the objects perceived at the time of generation.

The size of the CPM is dynamically calculated based on the number of containers in each CPM. The size of each container has been estimated offline using the ASN.1 definition of the CPM. To this aim, 10 000 standard-compliant CPMs considering only the mandatory Data Elements, varying the number of Sensor Information Containers and Perceived Object Containers have been generated. Using the generated ASN.1 messages, the average size of each container is computed as listed in Table 3.

Table 3: CPM Container sizes

CPM Container	Size in Bytes
ITS PDU header Management Container Station Data Container	121
Size per included Sensor Information	35
Size per included Perceived Object	35

5.3.3.2 Local Perception Sensors

The simulator ns3 has been extended with the local perception sensors described in clause 5.3.2.2 and depicted in Figure 3. Their range and field of view is summarized in Table 4. The sensor shadowing effect (sensor masking) is implemented in the XY-plane. It is assumed that the sensors can detect only the vehicles that are in their Line-of-Sight (LOS). In the sensor configuration 1, it is assumed that the objects detected by the two sensors are fused. Different scenarios have been simulated to analyse the impact of the range and field of view of the local perception sensors on the CPMs generated and the resulting channel load and awareness.

Table 4: Local perception sensors configurations

Configuration	Sensors
1 (Forward sensors)	Sensor 1: 65 m range and a field of view of ±40 degrees Sensor 2: 150 m range and a field of view of ±5 degrees
2 (360º sensor)	Sensor 1: 150 m range and a field of view of 360 degrees

5.3.3.3 Scenario

The traffic scenario considered in this study is a six-lane highway with 5 km length and a lane width of 4 meters (see Figure 7). Two different traffic densities following the 3GPP guidelines for V2X simulations [i.33] have been simulated: 120 veh/km and 60 veh/km. According to these guidelines, the high traffic density scenario has a maximum speed of 70 km/h, while the lower one has a speed limit of 140 km/h. For each traffic density, this study considers different speeds per lane, as shown in Table 5. The speeds have been selected based on statistics of a typical 3-lane US highway obtained from the PeMS database [i.34]. Vehicles measure 5 m × 2 m.

All vehicles are equipped with an ITS-G5 transceiver (100 % penetration rate) and operate in the control channel of the 5,9 GHz frequency band. This simulation study focuses on the evaluation of the CPS limiting the influence of other messages and protocols. To this aim, vehicles only transmit CPMs and the DCC is disabled. All transmitted messages are disseminated with the same priority on the MAC layer (Best Effort). The propagation effects are modelled using the Winner+ B1 propagation model following the 3GPP guidelines [i.33]. To avoid boundary effects, statistics are only taken from the vehicles located in the 2 km logging area in the centre of the simulation scenario.

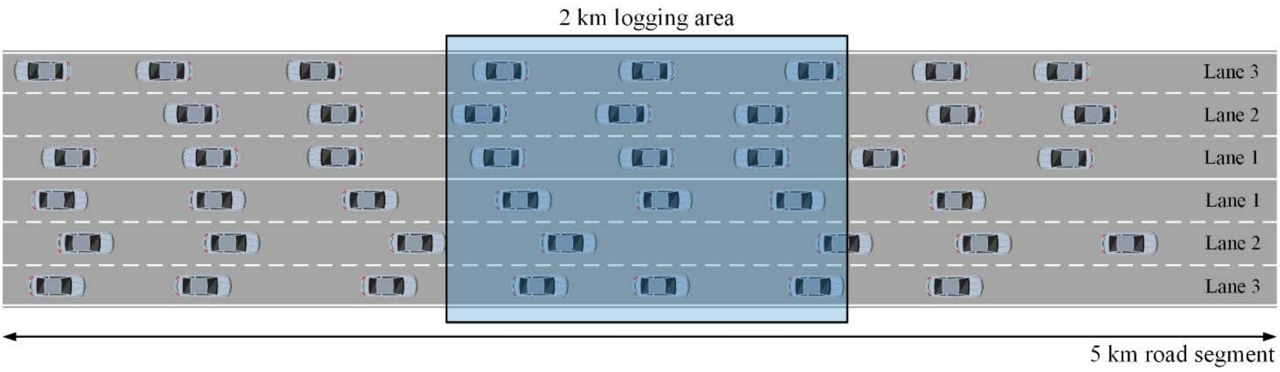


Figure 7: Highway scenario and logging area

Table 5: Scenario Parameters

Parameter	Values	
Traffic density (vehicles/km)	High 120	Low 60
Maximum speed per lane (km/h)	Lane 1: 70 Lane 2: 66 Lane 3: 59	Lane 1: 140 Lane 2: 132 Lane 3: 118

5.3.3.4 Parameterization of Simulation Study S2

Table 6 summarizes the main simulation parameters that have been fixed in this study. They have been selected following the 3GPP guidelines for V2X simulations [i.33] and the "Delegated Act" adopted by the European Commission for the deployment of C-ITS [i.35].

Table 6: Fixed Simulation Parameters

Parameter	Configuration
Data Bitrate	6 Mbit/s
Transmission Power	200 mW (23 dBm)
Antenna gain (tx and rx)	0 dBi
Radio Propagation Model	Winner+ B1 [i.33]
Channel bandwidth/carrier frequency	10 MHz/5,9 GHz
Noise figure	9 dB
Energy detection threshold	-85 dBm
Traffic scenario	5 km highway with 6 lanes (3 lanes per driving direction)
Market Penetration Rate	100 %
DCC configuration	Disabled
Radio Configuration	Single Channel (CCH)

Table 7 summarizes the simulation parameters that have been changed in this study to analyse their impact on the performance and efficiency of the CP Service. A full-factorial design results in a total of 16 configurations, where each configuration was run 10 times with different seeds (1 - 10) to ensure sufficient statistical accuracy, resulting in 160 simulations. The reasoning behind the selected configurations is:

- Different CPM generation rules are simulated. The generation rules defined in the present document will be referred to as *Dynamic* and *Dynamic-LA* (Look-Ahead). The generation rules defined as *Dynamic* are defined in clause 4.3 and do not consider any mechanism to reduce the number of CPMs generated. *Dynamic-LA* considers the mechanism defined in clause 4.3 and explained in clause 4.3.4.2 to reduce the number of generated messages. This mechanism offers the possibility to include in the currently generated CPM the objects that would need to be included in the next CPM generated at the next generation event. In addition to these two CPM generation rules, two *Static* generation rules that periodically generate CPMs at different frequencies (3 Hz and 10 Hz) are also evaluated.

- Two traffic densities have been considered. The traffic density can significantly affect the number of perceived objects, and therefore the number of objects included in each CPM. The increase of the traffic density decreases the vehicles speed, and can therefore impact the rate of the CPM generation with the generation rules defined in the present document.

- Different local perception sensor configurations have been analysed. The use of forward sensors or 360º sensors can significantly affect the number of perceived objects, and therefore the performance and efficiency of the CP Service.

Table 7: Variable Simulation Parameters

Parameter	Variations
CPM Generation Rules	• *Static (2 Hz)*: Complete message generated every 1 s (all containers), Minimum message generated every 500 ms (all containers except for Sensor Information Container) • *Static (10 Hz)*: Complete message generated every 1 s (all containers), Minimum message generated every 100 ms (all containers except for Sensor Information Container) • *Dynamic*: Proposed Generation rules (see clause 4.3) • *Dynamic-LA*: Proposed Generation rules with a mechanism to reduce the number of generated messages (see clause 4.3)
Traffic density (see clause 5.3.3.3)	• High: 120 vehicles/km • Low: 60 vehicles/km
Local perception sensors configurations (see clause 5.3.3.2)	Configuration 1: Forward sensors Configuration 2: 360º sensors

5.4 Evaluation/Aggregation Methodology

For both simulation studies, all simulation runs were assessed in a post-simulation processing step. This clause details the core metrics recorded as part of the simulations. Table 8 provides a summary of the recorded metrics. Each recorded data element for each metric is recorded along with a corresponding simulation timestamp, resulting in a collection of time-series for each vehicle.

As part of the post-simulation processing step, different statistical analyses were performed on these time-series in order to provide answers to the research domains outlined in clause 5.2. The recorded metrics are tailored at the analysis of the CP Service at the Facility-Layer.

Table 8: Overview of recorded metrics

Metric	Description
Channel Busy Ratio (CBR)	Time-dependent value between zero and one representing the fraction of time that a single radio channel is busy with transmissions [i.26]. In these simulations, it is always measured in the channel that is occupied by the CPM.
CP Message Rate	The number of CP Messages transmitted per second per vehicle.
CP Message Reception Timestamp	Records the timestamp whenever a CP Message has been successfully decoded by a receiving vehicle.
CP Message Size	The resulting message size of each generated CP Message. Associated to a message generation timestamp in the simulation.
CP Message Transmission Timestamp	Records the timestamp whenever a CP Message is transmitted by a vehicle.
Detected Object Redundancy	The number of updates received per second about the same object through the reception of CPMs.
Distance between Update for the same Object	Expresses the distance travelled by an object between updates for the same object. Computed for each object in a vehicle's environment model upon message reception.
Number and IDs of Known Objects per Sensor	Cyclically generated metric (every 100 ms) of all objects currently known to each vehicle with per sensor type (Radar, CAM, CPM). Each object is thereby characterized by a unique object ID within the simulation, the timestamp of the last object update and other state variables.
Number of CP Message Segments per Message Generation Event	Expresses the number of segments created whenever a CP Message generation event is triggered.
Number of Objects included per CP Message	The number of objects included in each generated CP Message. Associated to a message generation timestamp in the simulation.
Object Awareness Ratio	The probability to detect an object through the reception of a CPM with information about it in a given time window.
Packet Delivery Ratio (PDR)	The probability of successfully receiving a CPM as a function of the distance between the transmitting and receiving vehicles.
Speed Limit of Occupied Road	The speed limit of the road type currently occupied by a vehicle. Allows for classification of traffic scenarios: • 0 - 50 km/h: urban road. • 51 - 100 km/h: rural road. • Above 100 km/h: highway road.
Time between Update for the same Object	Expresses the time between updates for the same object. Computed for each object in a vehicle's environment model upon message reception.

5.5 Results

5.5.1 Assessing the Generation Rules

5.5.1.1 General Considerations

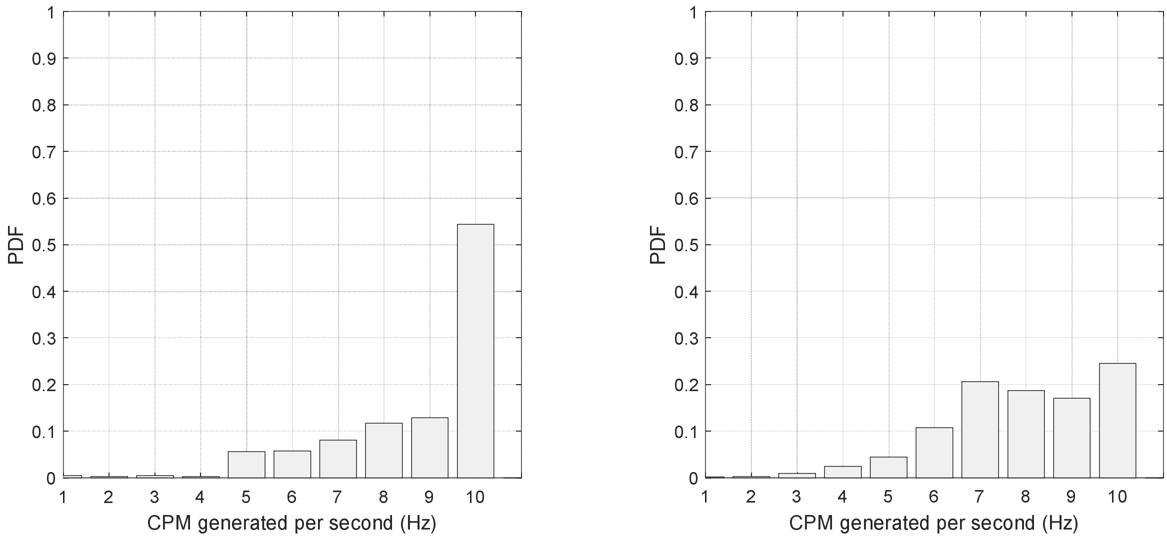
When transmitting informational messages, there is a trade-off between the generated channel load resulting from message transmission and the generated awareness. Both are expected to grow with increasing message transmission frequency and market penetration rate. The dynamic message generation rules detailed in clause 4.3 aim at reducing the channel load while maintaining the effectiveness of the CP Service. This is done by not only reducing the amount of objects included per CPM but also by reducing the number of overall transmitted CPMs. This clause analyses how well these rules perform when compared to much simpler, static generation rules that produce complete CPMs (i.e. including all objects known to the sender) at fixed rates.

5.5.1.2 Message rate and size

This clause is aimed at analysing the operation of the different CPM generation rule variations. It focuses on the dynamic policy first defined in the present document, without the look-ahead mechanism to reduce the number of CPMs generated per second as defined in clause 4.3. Figure 8 represents the Probability Density Function (PDF) for this policy of the number of CPMs transmitted per second per vehicle under two traffic densities when considering forward sensors. The number of CPMs generated per vehicle depends on the number of perceived objects (i.e., traffic density) and on their dynamics (e.g. an object is included in a CPM when its absolute position changes by more than 4m). One important aspect to take into account is the link between traffic density and vehicles' speed, since the speed of vehicles is higher for low traffic densities than for the high density scenario. As a result, vehicles satisfy more frequently one of the conditions specified in clause 4.3 for the dynamic CPM generation rules, and each vehicle individually generates more CPMs per second at low densities (Figure 8 (a)) than at high densities (Figure 8 (b)). However, not all vehicles generate CPMs at the same rate in a given traffic density scenario since the speed limit varies per lane (Table 5).

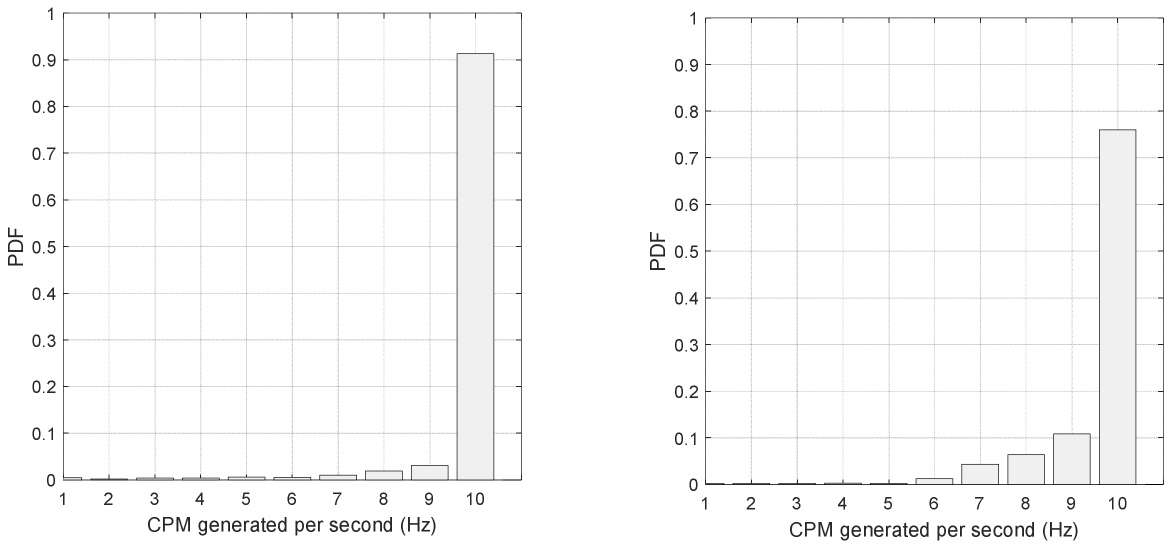
It is interesting to analyse with more detail the results shown in Figure 8 having in mind the vehicles' speed. In the low traffic density scenario, the vehicles that travel in the higher speed lane move at 140 km/h or 38,9 m/s. Similarly, in the low traffic density scenario, the vehicles that travel in the higher speed lane move at 70 km/h or 19,4 m/s. As a result, the fastest vehicles in the low traffic density scenario will change their absolute position by more than 4 m every 103 ms, and the fastest vehicles in the high traffic density scenario, every 206 ms. That means that these vehicles will be included in a CPM every 200 ms in the low traffic density scenario, and every 300 ms in the high traffic density scenario, because the conditions are checked every 100 ms. As a result, one should expect that the number of CPMs generated per second by a vehicle based on object mobility would be around 5 Hz in the low traffic density scenario, and around 3,3 Hz in the high traffic density scenario. However, Figure 8 shows that there are vehicles that transmit 5-10 CPMs per second. This effect is produced because a vehicle generates a CPM as soon as one of the perceived objects satisfies the conditions (e.g. changes its absolute position by more than 4 m) or a new object is detected. If the perceived objects (i.e. vehicles in this study) change their absolute position by more than 4 m at different times, the transmitting vehicle will need to generate different CPMs. This explains why CPM frequency rates as high as 10 Hz are observed in both traffic density scenarios.

Figure 9 depicts the PDF of the number of CPMs transmitted per second when considering 360º sensors. The comparison of the results in Figure 8 and Figure 9 shows an interesting effect produced by the different ranges and field of view of the different sensor configurations analysed. The use of 360º sensors in Figure 9 results in each vehicle perceiving a higher number of objects (i.e. vehicles in this study). As previously explained, perceived objects do not necessarily satisfy the conditions defined in clause 4.3 at the same time. As a consequence, the increase of the number of perceived objects results in an increase of the number of CPMs transmitted per second. As shown in Figure 9, vehicles transmit 10 CPMs per second most of the time when using 360º sensors, independently of the traffic density.



(a) Low traffic density **(b) High traffic density**

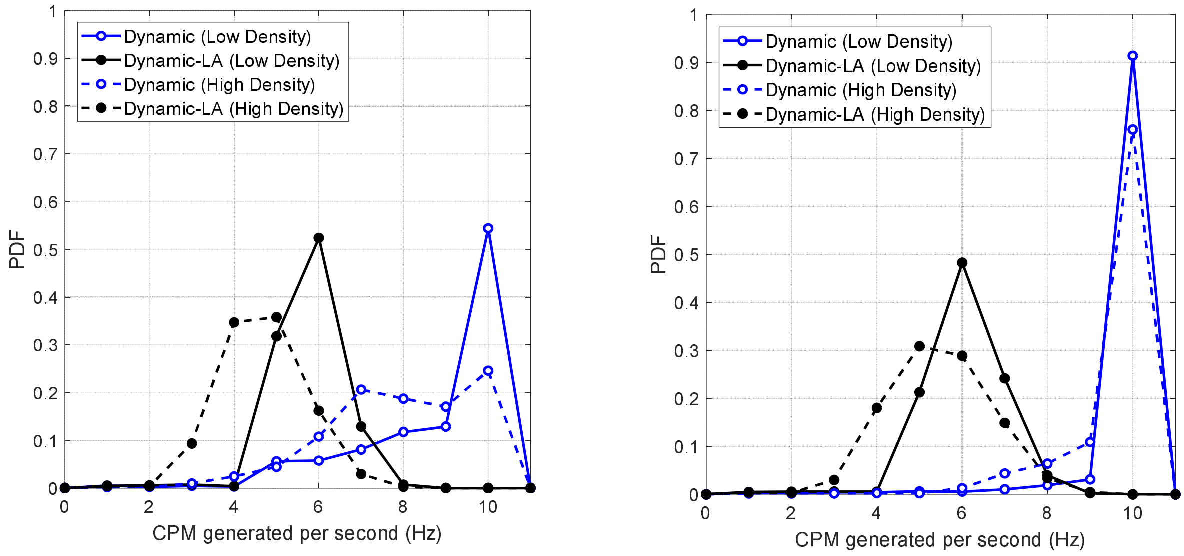
Figure 8: PDF (Probability Density Function) of the number of CPMs generated per second and per vehicle with the dynamic policy when considering forward sensors (S2)



(a) Low traffic density **(b) High traffic density**

Figure 9: PDF (Probability Density Function) of the number of CPMs generated per second and per vehicle with the dynamic policy when considering 360º sensors (S2)

Figure 10 compares the number of CPMs generated per second with the dynamic generation policy and without the mechanism defined in clause 4.3 to reduce the message frequency (referred to as *Dynamic-LA* and *Dynamic*, respectively). This mechanism considers that all objects that would need to be included in a CPM in the next generation event are selected for inclusion in the currently generated CPM. As it can be observed, this mechanism is able to significantly reduce the number of CPMs generated per second, independently of the traffic density and the type of sensors considered (forward or 360º sensors, in this case). As a result, the average number of CPMs generated per second is reduced between 34 % and 43 % with *Dynamic-LA* in the scenarios considered.

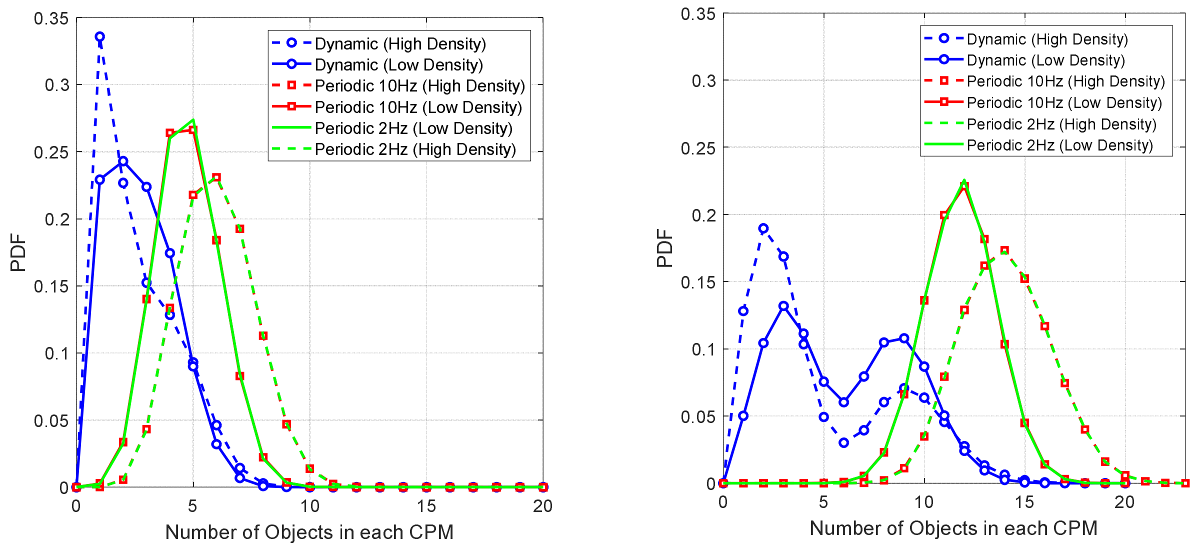


(a) Forward sensors **(b) 360º sensors**

Figure 10: PDF (Probability Density Function) of the number of CPMs generated per second and per vehicle with the dynamic policy (S2)

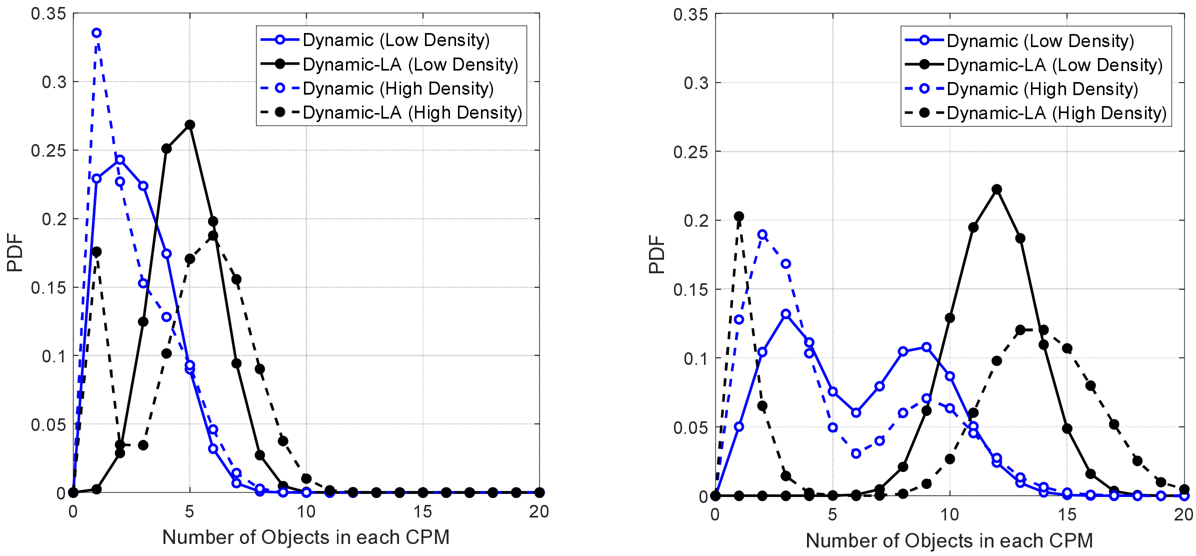
To understand the basic operation of the CPM generation rules, it is also interesting to analyse how many objects are included in each message. Figure 11 represents the PDF of the number of objects included in each CPM for the periodic and dynamic CPM generation policies under the two traffic densities considering forward sensors (Figure 11 (a)) and 360º sensors (Figure 11 (b)). The figure shows that the periodic CPM generation policies augment the size of CPMs since they include a higher number of detected objects per CPM. This is the case because the periodic policies always include in the CPM all the detected objects, while the dynamic policy selects the detected objects to be included in a CPM based on their dynamics. As the traffic density increases or the field of view and range of the sensors increase, the number of objects included in each CPM increases with the periodic policies because more objects (i.e. vehicles in our study) are detected. However, Figure 11 shows that the traffic density does not significantly affect the number of objects included in each CPM with the dynamic policy (both with forward and 360º sensors). This is the case because the speed of vehicles decreases as the traffic density increases. As a result, vehicles change their absolute position by more than 4 m less frequently. So even if each vehicle detects more surrounding vehicles due to the higher traffic density, the status of a detected vehicle needs to be reported in a CPM less frequently. The obtained results clearly show the benefits of the dynamic policy since it can adapt the number of objects included in each CPM to the traffic density and speed.

Figure 12 compares the number of objects included in each CPM with the dynamic generation policy with and without the mechanism previously described to reduce the message frequency. The results obtained show that the reduction of the CPM frequency with *Dynamic-LA* augments the number of objects per CPM. This mechanism reduces the number of CPMs transmitted with a small number of objects to increase the efficiency of the channel usage.



(a) Forward sensors **(b) 360º sensors**

Figure 11: PDF (Probability Density Function) of the number of objects included in each CPM with the dynamic and periodic policies (S2)



(a) Forward sensors **(b) 360º sensors**

Figure 12: PDF (Probability Density Function) of the number of objects included in each CPM with the dynamic policy (S2)

Finally, it is also important to analyse the distribution of the CPM size from a broader perspective considering the Luxemburg scenario that contains different types of roads and traffic densities. To this aim, Figure 13 shows boxplots of the observed message sizes resulting from the utilization of the static (10 Hz) and dynamic generation rules over the course of a day at 100 % market penetration for the SCO DP3 variant. Each box in the plot extends between the lower and upper quartile values of the data with the median indicated as the red line. The black lined whiskers extending from the box represent the reach of the data within 1.5 of the interquartile range. Red dots indicate outliers outside of this reach. The message size is aggregated over all the vehicles on all the road types. It varies with respect to traffic in the network, but the average size always stays well below the segmentation threshold of 1 100 bytes. The outliers indicate that segmentation may be required in specific situations although it was never necessary within the simulations of the Luxemburg scenario. Note that the dynamic generation rules always result in smaller messages when compared to the static generation rules, as also highlighted in Figure 11.

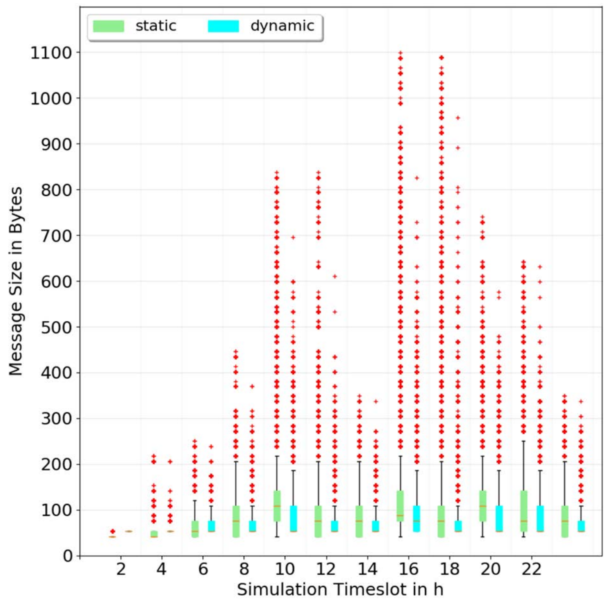
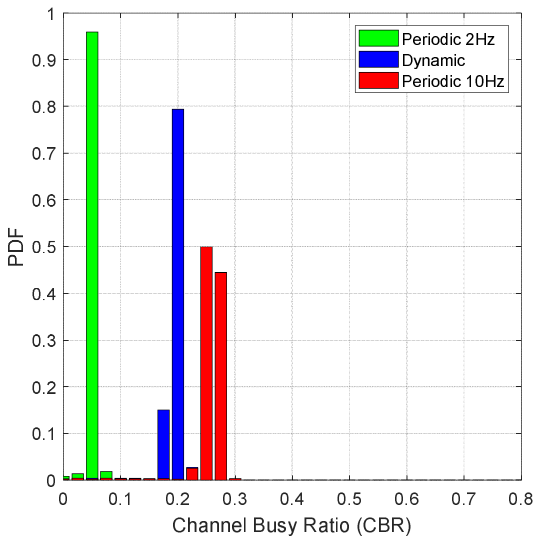


Figure 13: Message sizes for both generation rules throughout a day for the Luxemburg Scenario at 100 % market penetration rate (S1)

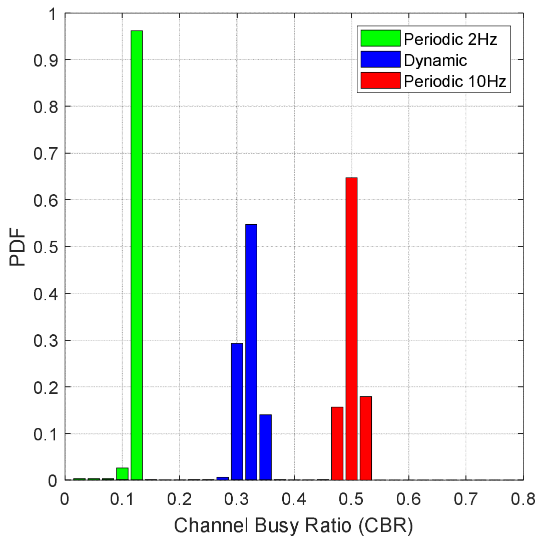
5.5.1.3 Channel Load

As a result of the message rate and size analysed in the previous clause, the CP Service will consume a certain portion of the radio channel. Given the congestion control problem of vehicular networks, it is therefore important to analyse the channel load consumed by the CP Service. Figure 14 shows the PDF of the CBR (Channel Busy Ratio) experienced when implementing each CPM generation policy under two traffic densities in the highway scenario when considering forward sensors. A high CBR value indicates that the channel is very congested. If this happens, the communications performance degrades and the packet delivery ratio decreases. The figure shows that the periodic policy operating at 2 Hz is the one generating the lowest channel load. On the other hand, the periodic policy at 10 Hz generates the highest channel load. The dynamic policy generates intermediate channel load levels, in line with the results depicted in Figure 8, Figure 9 and Figure 11. These results showed that the dynamic policy generates between 3 and 10 CPMs per second, approximately, and reduces the number of objects per CPM compared to the periodic policies. Consequently, the dynamic policy increases the channel load compared to a periodic policy at 2 Hz, but decreases it compared to the periodic policy at 10 Hz.

Figure 14 also shows that the CBR increases with the traffic density. However, lower increases are observed with the dynamic policy. In particular, an increase in the traffic density augments the average CBR experienced by the dynamic policy by a factor of 1,6, whereas it increases by factors of 2,1 (for 2 Hz) and 1,9 (for 10 Hz) for the periodic policies. This is again due to the same trend observed in Figure 8 and Figure 9. When the traffic density increases, the speed of vehicles decreases and vehicles change their absolute position by more than 4 m less frequently. As a result, vehicles generate less CP messages, and the CBR increase with the traffic density is lower for the dynamic policy than the periodic ones.



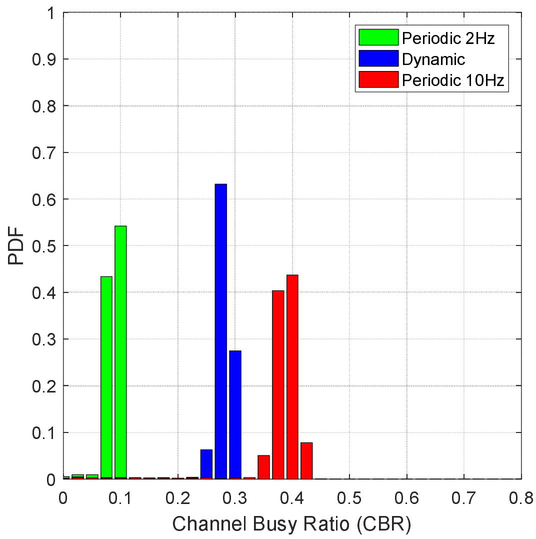
(a) Low traffic density



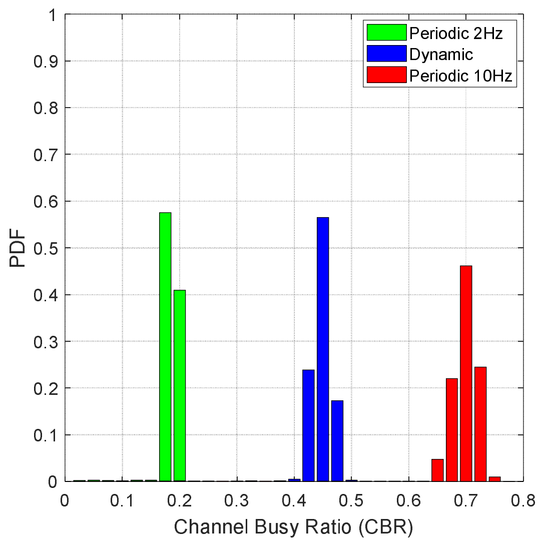
(b) High traffic density

Figure 14: PDF (Probability Density Function) of the CBR (Channel Busy Ratio) for the static and dynamic CPM generation policies for two traffic densities when considering forward sensors (S2)

Figure 15 shows the PDF of the CBR when considering 360º sensors. The comparison of the results in Figure 14 and Figure 15 clearly show an increase of the CBR when using 360º sensors compared to forward sensors. This is the case due to the higher number of perceived objects with the 360º sensors and the resulting higher message size and frequency (as already observed in Figure 8, Figure 9 and Figure 11).



(a) Low traffic density



(b) High traffic density

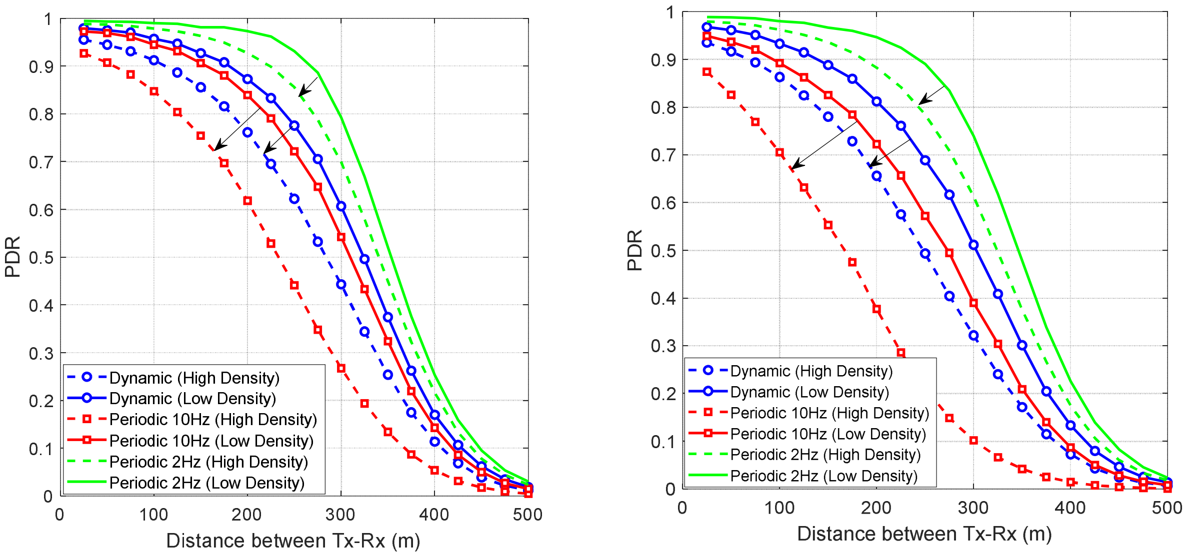
Figure 15: PDF (Probability Density Function) of the CBR (Channel Busy Ratio) for the static and dynamic CPM generation policies for two traffic densities when considering 360º sensors (S2)

Table 9 compares the average CBR experienced when considering the dynamic policy with and without the mechanism to reduce the message frequency. The results obtained show that reducing the message frequency with this mechanism (*Dynamic-LA*) can decrease the CBR between 10 % and 23 % approximately. This decrease is mainly due to the reduction of the transmission of headers (at different layers of the protocol stack) and containers related to the transmitting vehicle. More details about this effect are available in [i.42].

Table 9: Average CBR (Channel Busy Ratio) (S2)

Traffic Density	Policy	Forward sensors	360º sensor
Low	Dynamic	19,3 %	27,6 %
	Dynamic-LA	15,6 %	24,9 %
	Difference	-19,2 %	-9,8 %
High	Dynamic	31,8 %	44,4 %
	Dynamic-LA	24,4 %	38,2 %
	Difference	-23,3 %	-14,0 %

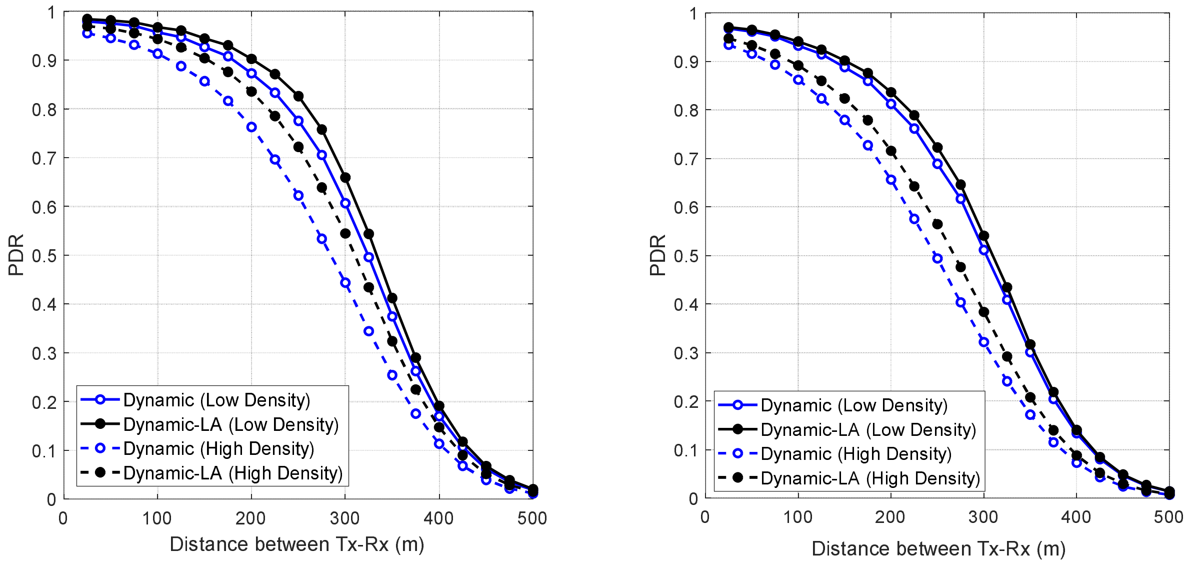
The channel load or CBR has an impact on the PDR (Packet Delivery Ratio), defined as the probability of successfully receiving a CPM as a function of the distance between the transmitting and receiving vehicles. Figure 16 plots the PDR of the periodic and dynamic CPM generation policies under the two traffic densities for forward and 360º sensors. The degradation of the PDR with the distance is due to the radio propagation effects. The PDR can also be degraded due to packet collisions or interference, especially when the channel load is high. This effect is highlighted in Figure 16 where the arrows indicate the degradation of the PDR as a result of an increase of channel load and packet collisions when the traffic density (and the CBR) increases. Figure 14 and Figure 15 already showed how the channel load increases with the traffic density. The resulting PDR degradation observed in Figure 16 is hence a consequence of the trends observed in Figure 14 and Figure 15. Following these trends, Figure 16 shows that the periodic policy operating at 2 Hz achieves the highest PDR and the policy at 10 Hz the lowest one. Figure 16 also highlights that the dynamic policy achieves a balance between the two periodic policies. The figure also shows the higher degradation of the PDR observed when using 360º sensors due to the higher CBR and therefore higher interference levels and packet collisions.



(a) Forward sensors **(b) 360º sensors**

Figure 16: PDR (Packet Delivery Ratio) as a function of the distance between transmitter and receiver (S2)

Figure 17 shows that the PDR can be improved if the look-a mechanism to reduce the message frequency is considered in the dynamic policy, i.e. with *Dynamic-LA*. This improvement is due to the reduction of the CBR and the resulting reduction of the number of packet collisions. The PDR is improved independently of the traffic density and type of sensor. The improvement of the PDR is especially higher for higher traffic densities, given the higher CBR gain achieved with this mechanism in these scenarios.

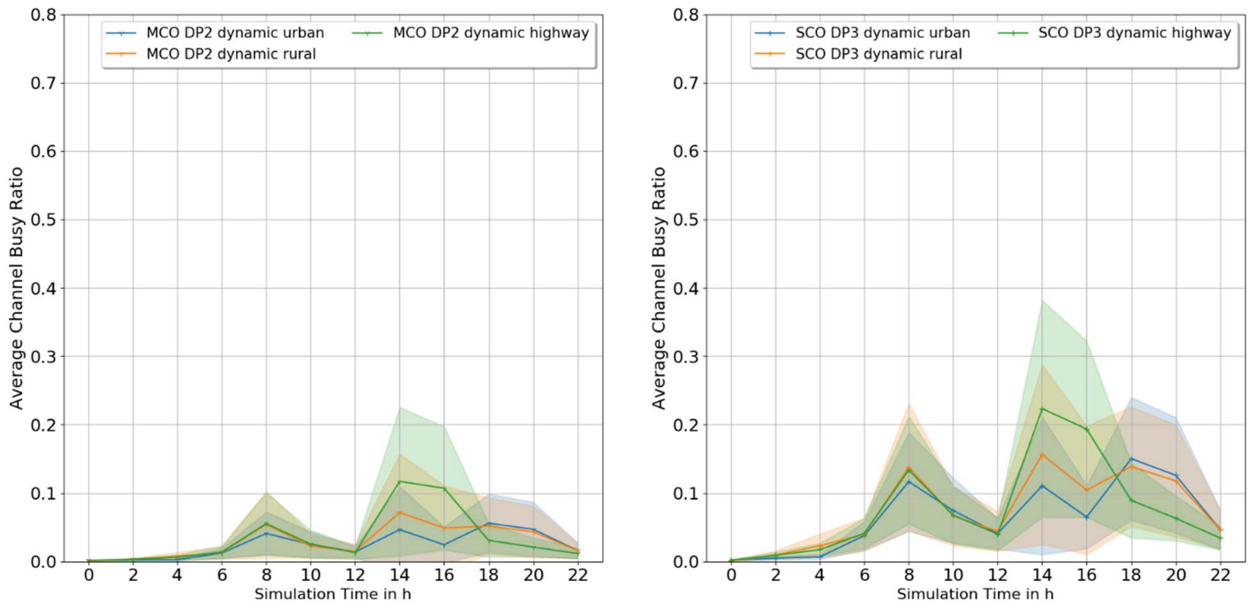


(a) Forward sensors **(b) 360º sensors**

Figure 17: PDR (Packet Delivery Ratio) as a function of the distance between transmitter and receiver for dynamic policies (S2)

When analysing one complete day of traffic in the case of the Luxemburg Scenario, the number of vehicles on the roads varies with respect to the time of day, and with that the resulting channel load (see Figure 5). At the two rush-hour times in the morning and in the afternoon, the maximum channel load can be observed. The diagrams show the Channel Busy Ratio (CBR) measurements ($\mu \pm \sigma$) reported by all the vehicles in the respective time slots, averaged per road type at 100 % market penetration rate. All vehicles were using the dynamic generation rules. Figure 18 (a) shows this for the Multi-Channel transmission variant which therefore only includes channel load created by the CPM itself. It is evident that the urban areas exhibit the lowest CBR whereas the highest CBR is seen on the highways. This is expected since the dynamic generation rules include perceived objects based on their dynamics. The more dynamic the vehicles, the more often they are included in CPMs generated by observing ITS-Ss. This leads to both larger and more frequently sent CPMs which in turn increases the channel load. The exception to this behaviour is in the evening were highways are congested due to people leaving the city and hence vehicles are only able to proceed slowly.

The same effects are to be found in Figure 18 (b), showing the SCO DP3 transmission variant. In this scenario, the CAM also contributes to the channel load. Since the rationale behind the CAM's generation rules is similar to the CPM's, i.e. they base on the dynamic state of the respective vehicles (or observed objects), the effects explained above are exaggerated and the increased observed CBR is a result of two messages sharing the same communication channel.



a) MCO **b) SCO DP3**

Figure 18: Average channel busy ratio throughout a day for MCO and SCO DP3 transmission variants on different road types for the Luxemburg scenario at 100 % market penetration rate (S1)

Figure 19 depicts boxplots of the observed CBRs for different market penetration rates at 08:00 in the morning for the SCO DP3 variant. As to be expected, the observed CBR increases with increasing market penetration rate as the number of transmitted messages increases. It is evident that the dynamic generation rules generally reduce the CBR by about 35 - 50 % compared to the static generation rules.

To compare the generation rules in more detail, Figure 20 (a) shows boxplots of the CBR for different road types for the SCO DP3 variant with 100 % market penetration rate again, but this time only in the rush-hour slot at 08:00 in the morning. In general, utilization of the dynamic generation rules reduces the observed channel load by about 50 % compared to the static rules. However, depending on specific traffic scenarios, very high channel loads can be observed for both rules as outliers indicate. The different CBRs of the different generation rules result from the number of generated messages on the one hand but also from smaller messages on the other hand. The messages are smaller because they include less objects as indicated in Figure 20 (b) which depicts boxplots for the number of objects per CPM resulting from the same simulation configuration as used for Figure 20 (a). It can be observed that urban environments exhibit the least amount of objects included in a specific message when compared to the more dynamic driving environments. Note that the simulation only included vehicles and no other objects or VRUs. In real-life, especially in urban areas, there will be many VRUs which will be included at a high rate due to the dynamic generation rules. However, in general, the dynamic generation rules result in a reduced number of objects per message and therefore in a reduced message size.

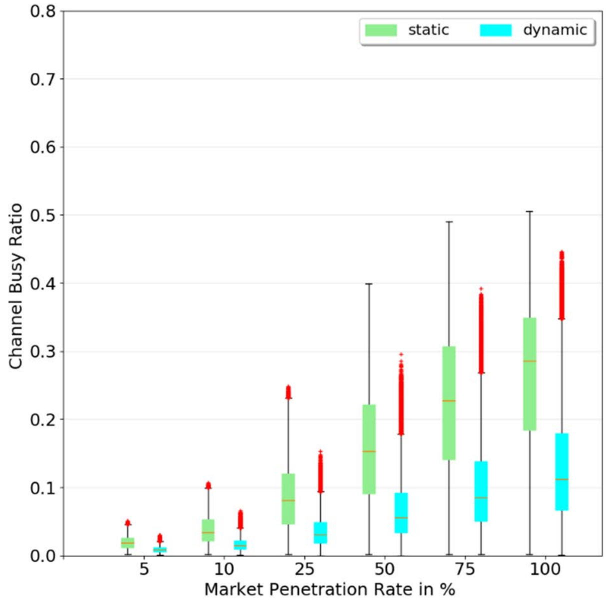
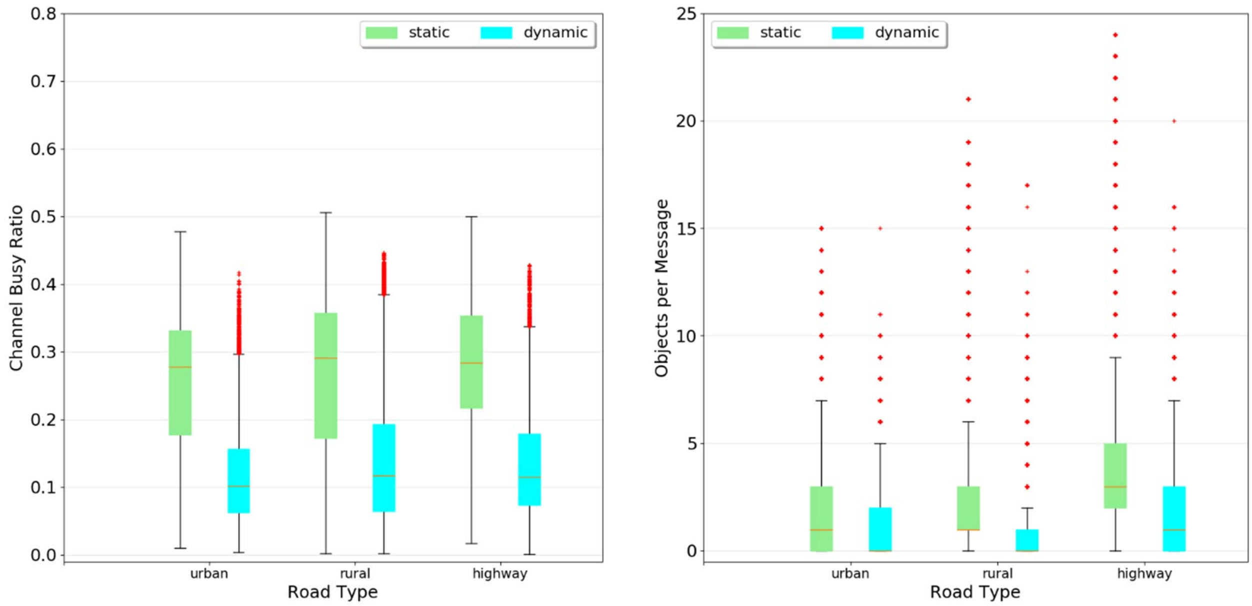


Figure 19: Comparison between the static and dynamic generation rules for the Luxemburg Scenario at varying market penetration rates (S1)



(a) Boxplot of CBR for static and dynamic message generation rules

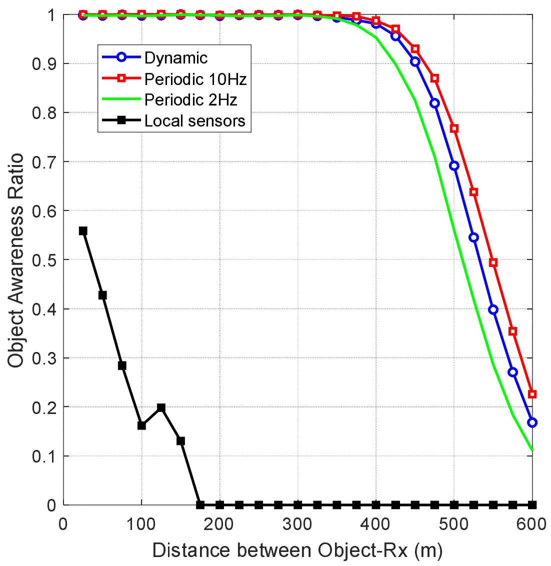
(b) Boxplot of the total number of perceived objects included in transmitted CPMs

Figure 20: Comparison between the static and dynamic generation rules for the Luxemburg Scenario at 08:00 and 100 % market penetration rate for different road types (S1)

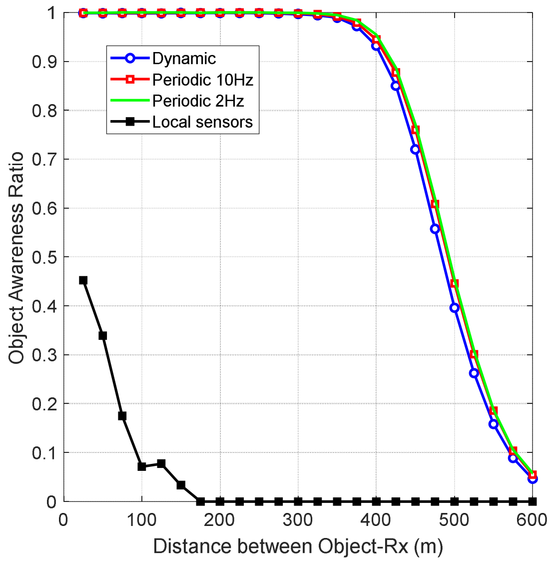
5.5.1.4 Awareness

The dynamic generation rules can make a more efficient use of the radio channel than the periodic approaches by not including all possible objects in every CPM, thereby reducing the resulting message size. Another effect of not including all objects in every CPM as a result of the dynamic generation rules is that the general amount of transmitted CPMs is reduced compared to the 10 Hz periodic approach because oftentimes there are simply no objects to be included and hence no CPM is sent at all. This can of course be at the cost of situation awareness at the receivers. It is therefore important to evaluate the awareness generated by the CPM when varying the generation rules and thus resulting object update rates.

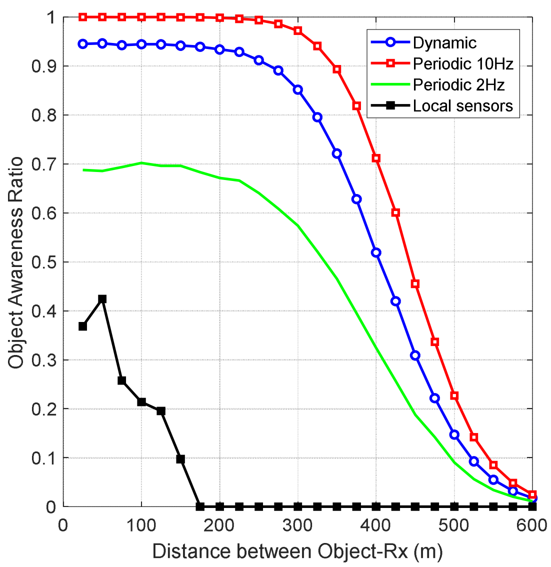
This clause analyses the perception capabilities of vehicles as a result of the different CPM generation policies. To this aim, the object awareness ratio is defined as the probability to detect an object (vehicle in this study) through the reception of a CPM with its information in a given time window. It is considered that an object is successfully detected by a vehicle if it receives at least one CPM with information about that object within a given time window. The object awareness ratio is computed for a time window of 1 s and 0,1 s (non-overlapping windows). Figure 21 depicts the average Object Awareness Ratio as a function of the distance between the object and the vehicle receiving the CPM with information about it, when considering forward sensors. The results are shown for the periodic and dynamic policies, the two traffic densities and different observation windows for the awareness ratio. The figure also includes the probability of detecting an object by the local sensors, which have limited range and field of view and can be masked by nearby vehicles. Note that in case of the 1 s observation window, vehicles are more likely to perceive a higher number of unique perceived objects, resulting in the slightly increased awareness ratio for this observation window. The results obtained clearly show the awareness gain obtained with the CP Service compared with just using the local sensors. The results obtained in Figure 21 show that when the time window is equal to 1 s all policies achieve a high object awareness ratio (higher than 0,987) up to 300 m (see Figure 21 (a) and (b)) independently of the traffic density. The awareness ratio degrades under higher densities for the dynamic policy and the periodic policy at 10 Hz due to the CBR increase produced at higher densities. At lower densities, the degradation of the object awareness ratio beyond 350 m is higher for the periodic approach at 2 Hz. This is due to the fact that at such distances the propagation effect becomes dominant when the traffic density is low (there are less packet collisions). All CPM generation policies experience the same degradation due to the propagation since it is not dependent on the channel load. However, propagation losses affect more negatively the object awareness ratio for the periodic policy at 2 Hz since this policy transmits less CPMs. To further study these effects, Figure 21 (c) and Figure 21 (d) show the object awareness ratio for all the policies when the time window used to compute it is set to 0,1 s. In this case, the periodic policy at 2 Hz cannot achieve a high object awareness ratio performance even at short distances due to the low number of CPMs generated per second. The results show that only the periodic policy at 10 Hz can achieve an object awareness ratio close to 1 at short distances under this scenario where the time window is set to 0,1 s. The dynamic policy, that compromises on CPM generation rate to reduce the channel load and therefore improves the communications performance compared to the periodic policy at 10 Hz, degrades the object awareness ratio, but still achieves a performance above 90 % and 80 % up to 200 m under low and high traffic densities, respectively, for a time window 0,1 s.



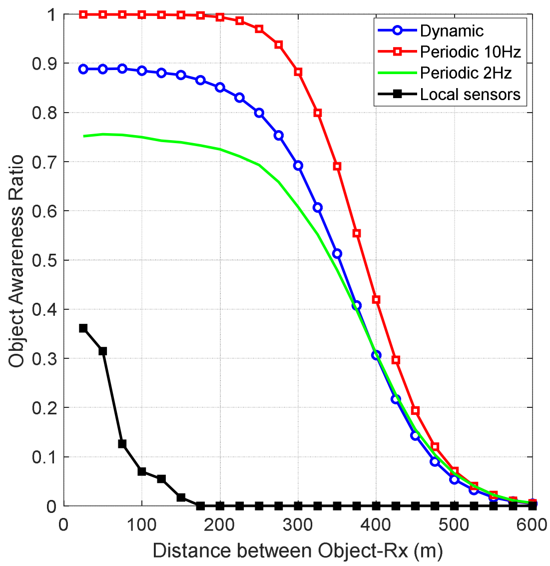
(a) Time window of 1 second (low density)



(b) Time window of 1 second (high density)



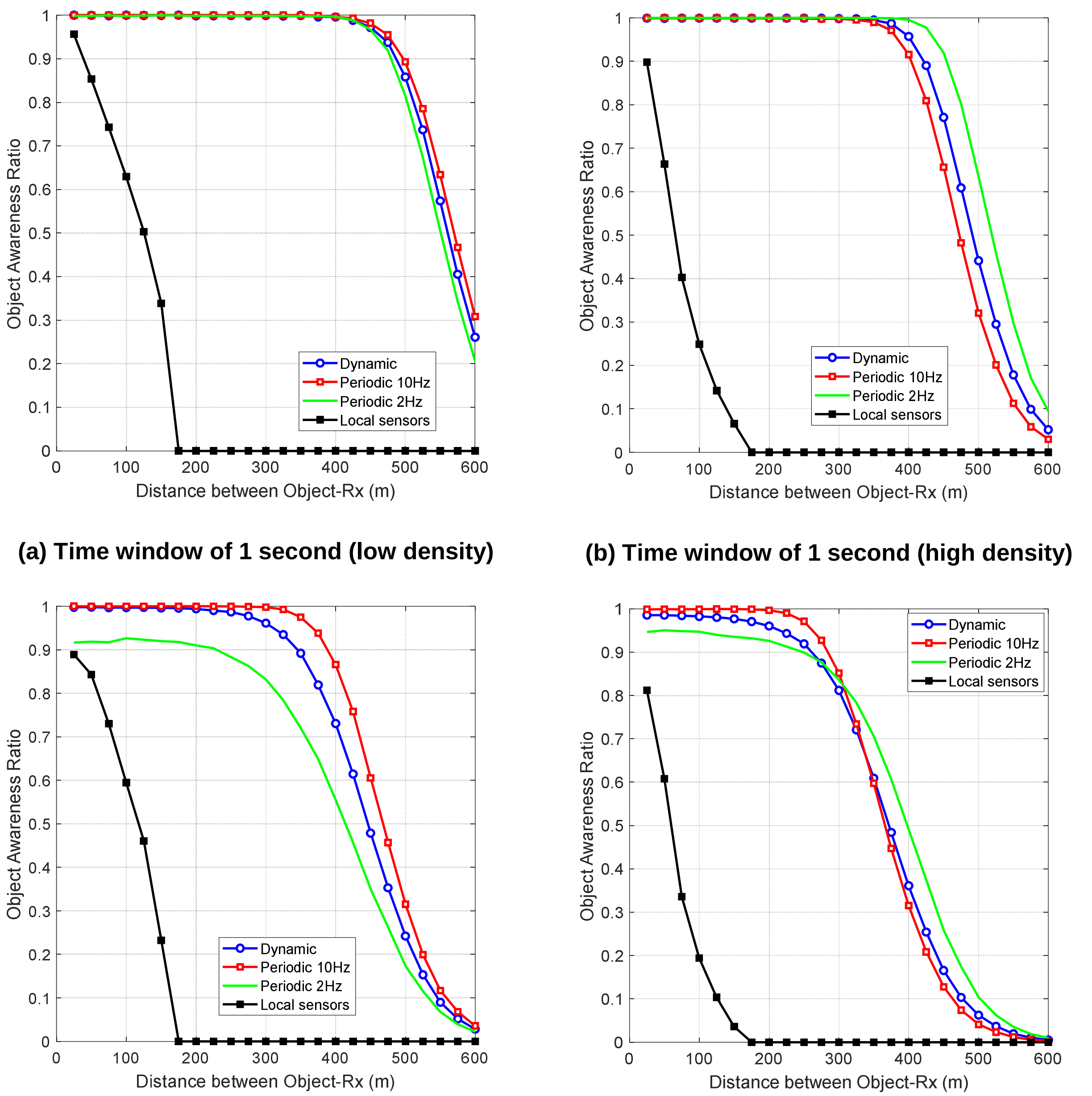
(c) Time window of 0,1 seconds (low density)



(d) Time window of 0,1 seconds (high density)

Figure 21: Object Awareness Ratio as a function of the distance between the detected object and the vehicle receiving the CPM when considering forward sensors (S2)

Figure 22 plots the Object Awareness Ratio when considering 360º sensors. These sensors improve the local perception of vehicles (i.e. without the use of CPMs), but the exchange of CPMs produces again a significant gain. Vehicles using 360º sensors are able to perceive and report the presence of more objects, including them in CPMs. Since more vehicles are reporting information about each object, the object awareness ratio is improved compared to the scenario when the forward sensors are used. The results in Figure 22 show that the object awareness ratio is close to 1 for distances higher than 350 m when considering a time window of 1 s. When the time window considered to compute the object awareness ratio is 0,1 s, the object awareness ratio decreases, but it is still close to 1 for the dynamic generation rules for distances up to around 200 m for the low density scenario, and above 0,95 for the high density scenario.

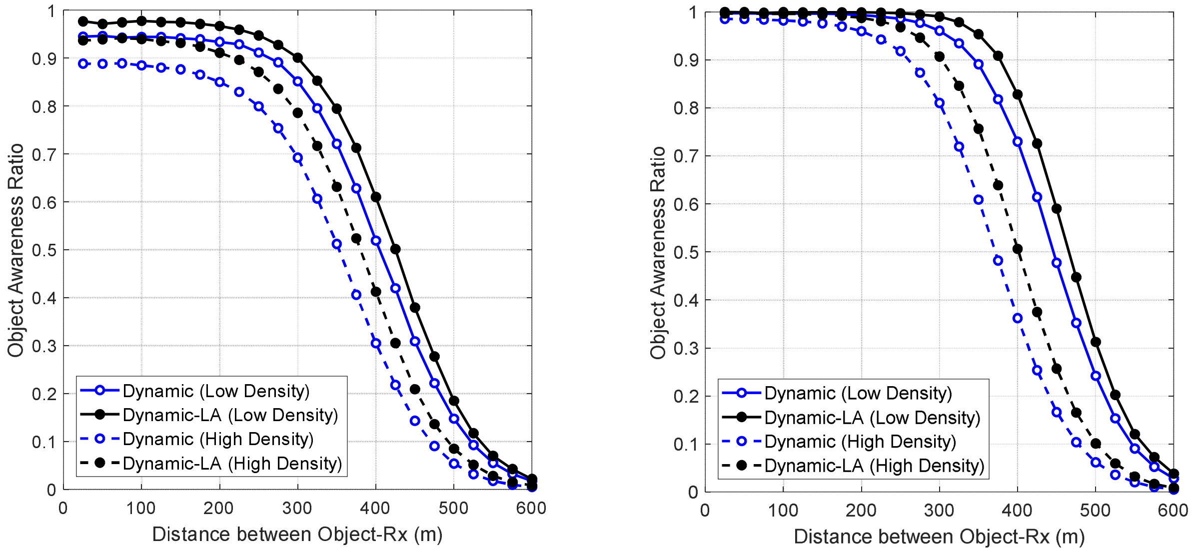


(a) Time window of 1 second (low density) **(b) Time window of 1 second (high density)**

(c) Time window of 0,1 seconds (low density) **(d) Time window of 0,1 seconds (high density)**

Figure 22: Object Awareness Ratio as a function of the distance between the detected object and the vehicle receiving the CPM when considering 360º sensors (S2)

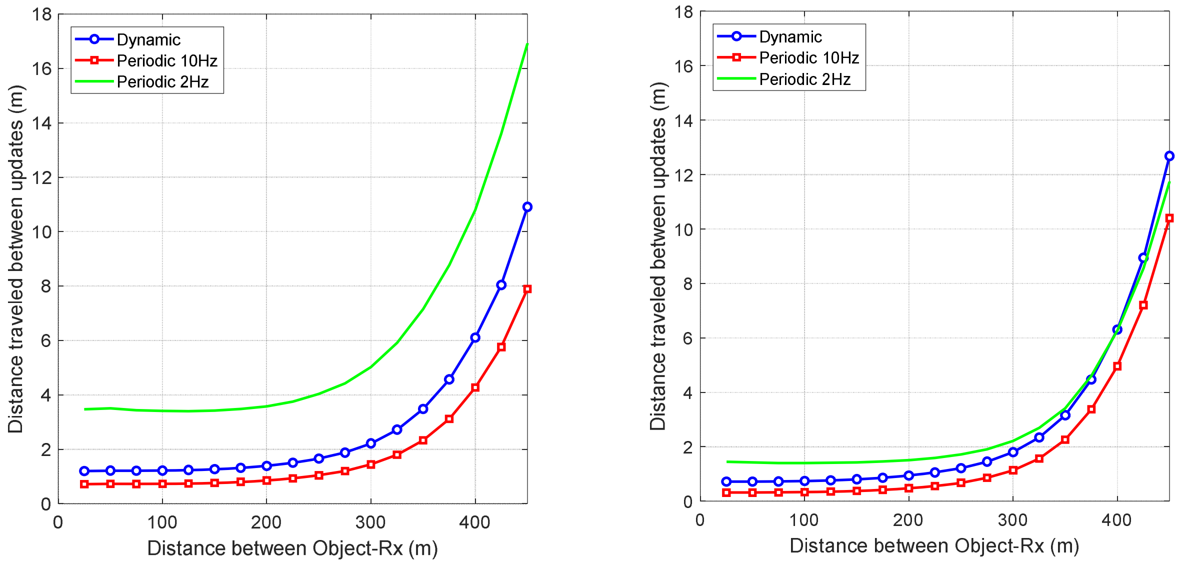
Figure 23 extends the previous analysis comparing the object awareness ratio achieved when considering the dynamic generation policy with (*Dynamic-LA*) and without (*Dynamic*) the look-ahead mechanism previously described to reduce the message frequency. As it can be observed, this mechanism improves the object awareness ratio achieved independently of the traffic density and the type of sensor considered. This improvement is due to two main reasons. The first one is the fact that *Dynamic-LA* increases the PDR and therefore the probability to correctly receive CPM messages increases. The second reason is that *Dynamic-LA* reorganizes the transmission of detected objects in CPMs. This reorganization results in a lower number of transmitted CPMs and an increase (between 11 % and 21 %) in the average number of times that a detected object is reported in a CPM. This also has a positive impact on the perception capabilities and hence on the object perception ratio. The results in Figure 23 have been obtained for a time window of 0,1 s, but the same trends are obtained when considering a time window of 1 s.



(a) Forward sensors **(b) 360º sensors**

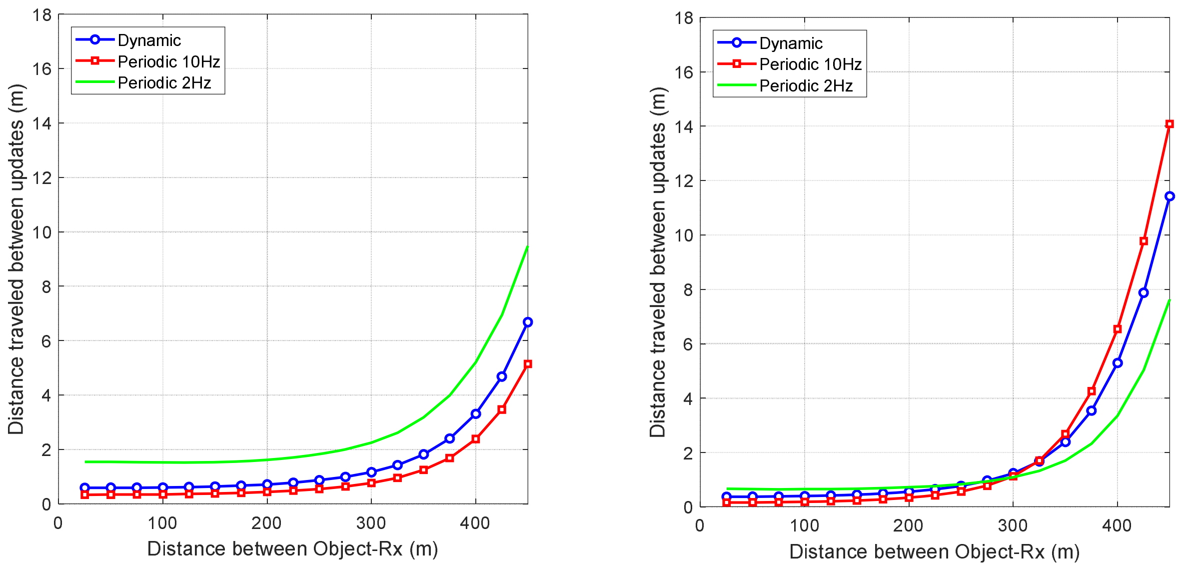
Figure 23: Object Awareness Ratio as a function of the distance between the detected object and the vehicle receiving the CPM when considering dynamic policies and a time window of 0,1 s (S2)

The value of collective perception depends on how timely or fresh is the information received about the detected objects. A vehicle cannot base its driving decision on outdated information. Figure 24 plots the distance travelled by objects between two successive received CPMs with information about the same object or vehicle. In this case, the metric is named distance travelled between updates and is represented as a function of the distance between the object and the vehicle receiving the CPMs for both low and high traffic densities when considering forward sensors. It is important to emphasize that the CPMs including information about the same object or vehicle might be transmitted by different (multiple) vehicles. Figure 24 shows that the periodic generation policy at 2 Hz approximately provides updates of objects that have travelled less than 4 meters in the low density scenario and 2 m in the high density scenario, for distances between the objects and the vehicle receiving the CPMs up to 250 meters. These values reduce to 1,6 m (low density) and 1,25 m (high density) with the dynamic policy. More frequent updates are provided by the periodic approach at 10 Hz due to the higher CPM transmission frequency. The periodic approach at 2 Hz provides the worst results when measuring the distance travelled between updates despite generating the lowest channel load. The dynamic generation rules are able to balance the load generated and the achieved awareness. Similar trends are observed in Figure 25 but considering 360º sensors. However, when using 360º sensors, each object is detected by a higher number of vehicles. As a result, each object's position and speed is reported more frequently in the vehicular network. This significantly decreases the distance travelled between object updates.



(a) Low traffic density **(b) High traffic density**

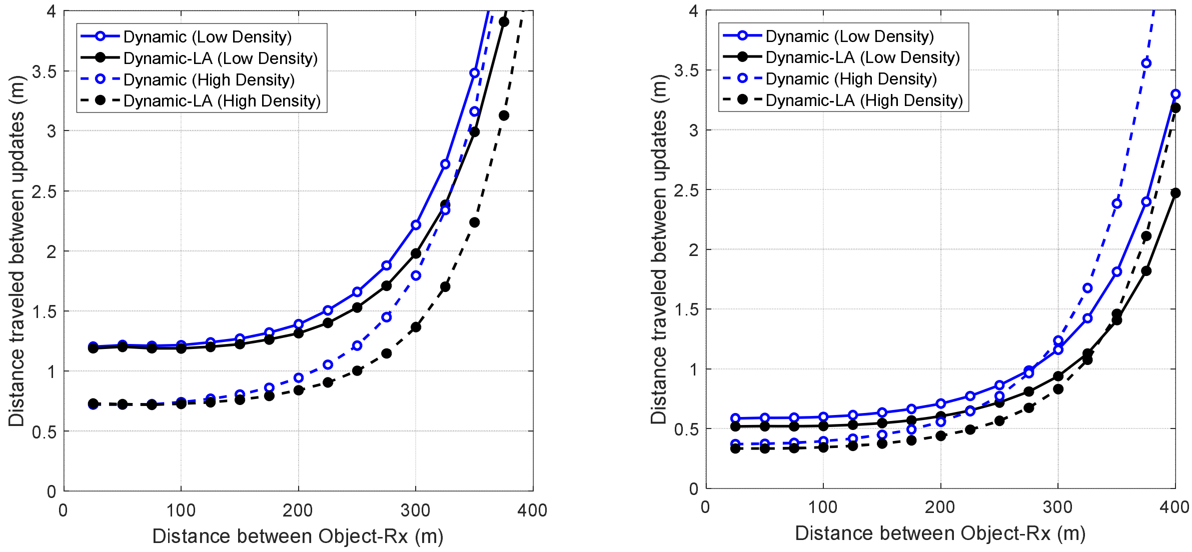
Figure 24: Average distance travel of an object between updates as a function of the distance between the detected object and the vehicle receiving the CPM when considering forward sensors (S2)



(a) Low traffic density **(b) High traffic density**

Figure 25: Average distance travel of an object between updates as a function of the distance between the detected object and the vehicle receiving the CPM when considering 360º sensors (S2)

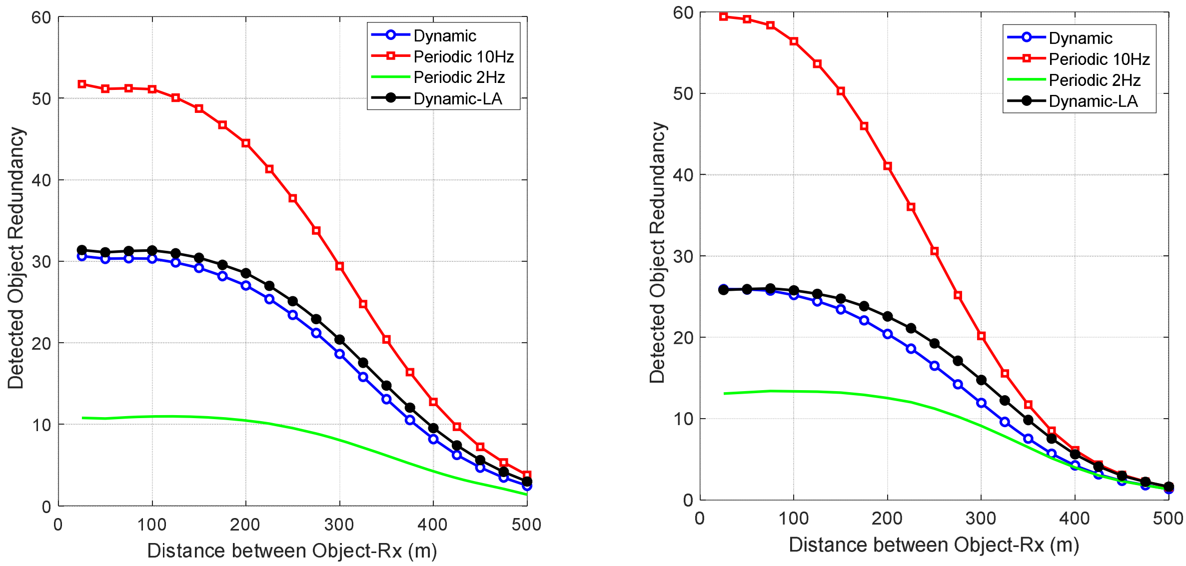
Figure 26 compares the distance travelled by objects between two successive received CPMs when considering the dynamic policy with and without the look-ahead mechanism to reduce the message frequency. As it was expected based on the previous analysis of the object awareness ratio, the *Dynamic-LA* approach also improves the distance between object updates, independently of the traffic density and type of sensor considered. This improvement is due to the improvement in the PDR and also to the fact that objects are slightly more frequently transmitted when considering the mechanism to reduce the message frequency.



(a) Forward sensors **(b) 360º sensors**

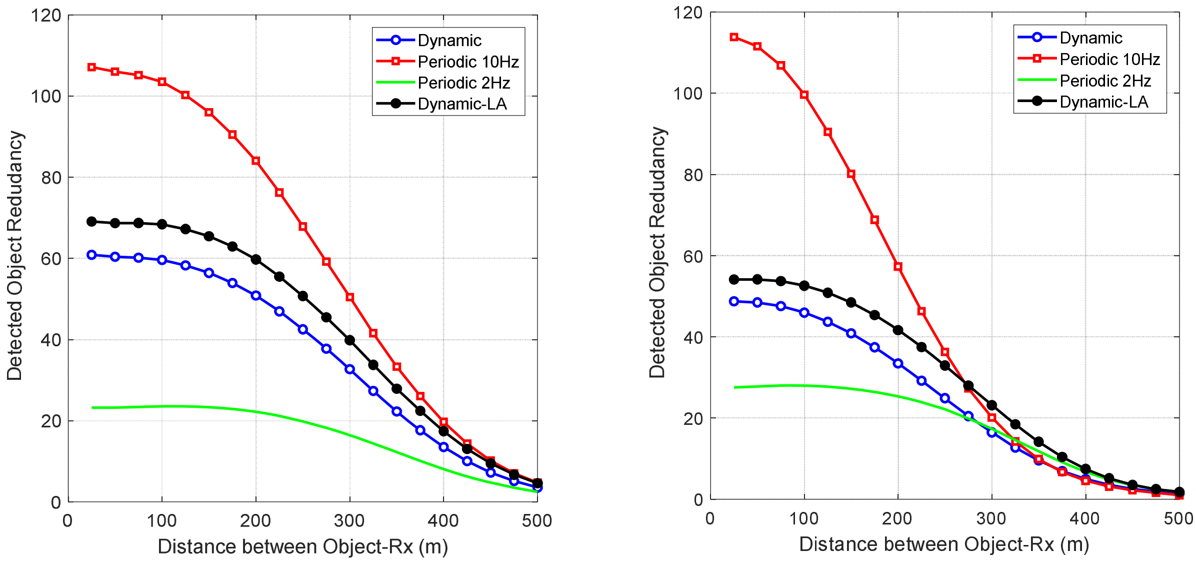
Figure 26: Average distance travel of an object between updates as a function of the distance between the detected object and the vehicle receiving the CPM when considering dynamic policies (S2)

The obtained results show that all CPM generation rules provide high object awareness ratios and low travelled distances between updates. However, it has been shown in Figure 14 and Figure 15 that the CPM generation policies can generate non-negligible channel load levels that can degrade the communications performance and impact the network's scalability. Figure 27 and Figure 28 depict the number of updates received per second about the same object through the reception of CPMs for forward and 360º degree sensors. This metric is referred to as detected object redundancy and is depicted as a function of the distance between the object and the vehicle receiving the CPM for both low and high traffic densities. Figure 27 shows that the periodic policy at 10 Hz provides around 55 updates per second of the same object at short distances in the low density scenario, and around 59 updates per second in the high density scenario. The dynamic policy reduces this value to 25 - 30 updates per second (with and without considering the mechanism to reduce the message frequency). The degradation observed in Figure 27 and Figure 28 with the distance is a direct consequence of the PDR degradation. Figure 28 shows that the use of 360º sensors can significantly increase the observed redundancy. The comparison of the results in Figure 27 and Figure 28 show that the redundancy is almost doubled with 360º sensors at short distances.



(a) Low traffic density **(b) High traffic density**

Figure 27: Detected object redundancy as a function of the distance between the detected object and the vehicle receiving the CPM when considering forward sensors (S2)



(a) Low traffic density **(b) High traffic density**

Figure 28: Detected object redundancy as a function of the distance between the detected object and the vehicle receiving the CPM when considering 360º sensors (S2)

Figure 29 shows a boxplot for the number of objects vehicles are aware of as a result of them receiving a CPM which included the respective vehicle as a *Perceived Object*. The evaluation does not take into account whether the objects were known to the receivers beforehand due to CAMs or because of their own local perception sensors as the effectiveness of the CPM is independent of that. The plot shows data from the Luxemburg scenario at 08:00 in the morning at a market penetration rate of 100 %. Independent of the employed transmission variant, the number of known objects is generally comparably high for both generation rules, although it is highest for the MCO variant. More details on that comparison are provided in clause 5.5.2.

In order for the CP Service to be effective (i.e. provide high quality data to its applications), not only is the amount of objects an important criterion but also is the time between updates for a unique object. Figure 30 shows the Cumulative Distribution Function for the time between object updates in the Luxemburg scenario at 08:00 in the morning depending on varying market penetrations, transmission variants and generation rules - the latter of which is the focus of this comparison. It is evident that the static generation rules exhibit a very low mean time between updates - almost independent of the other variables. For the dynamic generation rules, it can be inferred that the time between updates decreases with increasing market penetration rates. This is expected as with increasing market penetration, there is an increasing number of vehicles transmitting CPMs including the same object. Therefore, updates for those objects are received at a rate higher than the rate ITS-Ss transmit CPMs at. Nevertheless, at the benefit of decreased channel utilization and smaller message sizes, the update rate for the dynamic generation rules is lower when compared to the static rules.

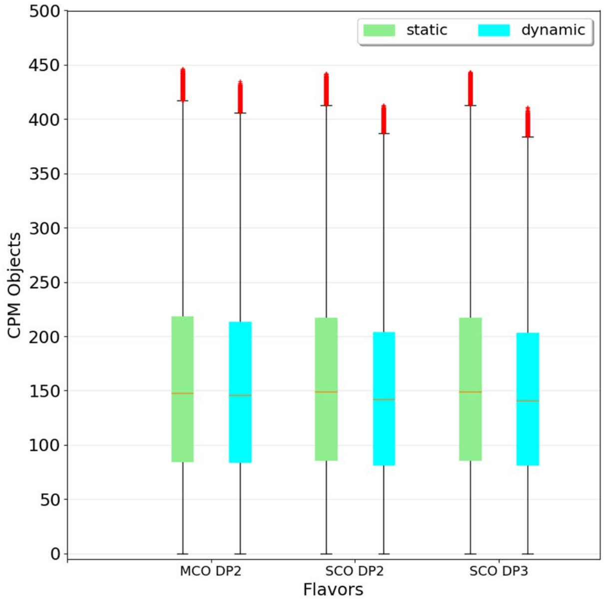


Figure 29: Number of objects known to a host vehicle due to receiving them in a CPM (S1)

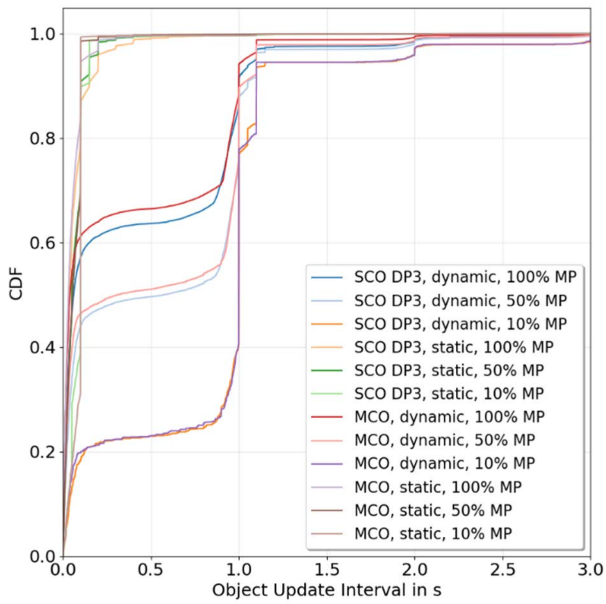


Figure 30: Time between updates for unique objects for different transmission variants, generation rules and market penetration rates (S1)

5.5.1.5 Summary

The results obtained in the two simulation studies conducted demonstrate that the dynamic generation rules defined in the present document are able to provide a balance between channel load and awareness compared to periodic message generation solutions. The dynamic selection of the objects that are included in each CPM reduces the message size while performing similarly to static rules in terms of inter-object update times. The dynamic generation rules take into account the vehicles' dynamics and is more scalable than the periodic approaches that include all the perceived objects in all CPMs. As a result, the dynamic generation rules reduce the channel load generated compared to a periodic solution operating at 10 Hz, especially when considering the mechanism to reduce the CPM frequency (this mechanism can both reduce the channel load generated and improve the awareness). Although the periodic approach is able to outperform the dynamic generation rules proposed in terms of awareness, it comes at the cost of significantly higher channel load. Further analysis would be needed to understand the potential benefits (if any) of the higher awareness achieved by the periodic approach operating at 10 Hz, since the interference generated is much higher than for the dynamic generation rules. A periodic approach operating at 2 Hz reduces the load compared to the dynamic approach, but the achieved awareness is lower. The results obtained have also demonstrated a high impact of the range and field of view of the local sensors on the channel load generated and awareness levels observed.

5.5.2 Variation of DCC Parameters and Radio Configurations

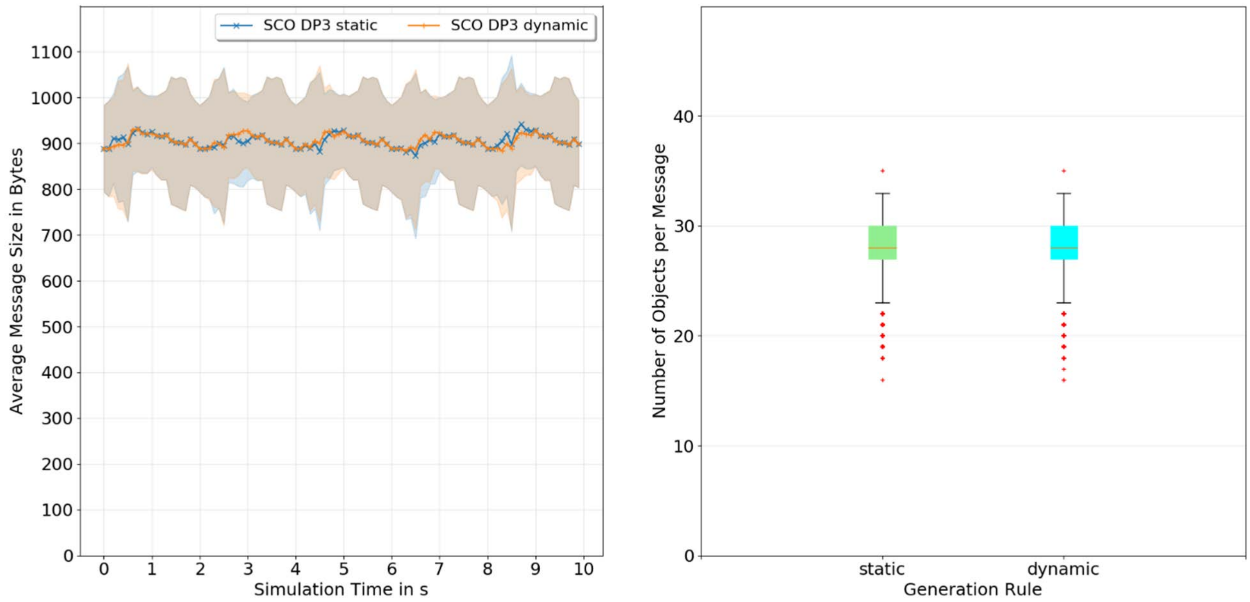
5.5.2.1 General Considerations

Another aspect evaluated by the simulation study was the effect of the different transmission configurations outlined in Table 2. Three different configurations have been studied - in all configurations, the transmission settings of the CAM comply with ETSI EN 302 637-2 [i.7]: The first single-channel configuration transmits both CAMs and CPMs in the Control Channel (CCH) with a DCC Profile priority level DP2 [i.7]. The second single-channel configuration maintains the settings for CAM dissemination, but utilizes the lower priority level DP3 for CPM transmission on the Control Channel (CCH). The third configuration provides a multi-channel option by disseminating the CAM on the Control Channel with a priority of DP2; the CPM is transmitted on the separate Service Channel 1 (SCH1) also with a priority of DP2. The rationale behind these settings is to assess the effect of different radio configurations on both the performance of the CP Service as well as on the resulting channel utilization. This first configuration is added as a baseline comparison, albeit only the CAM is allowed to employ the DP2 priority.

The majority of the findings presented in the following subsections employ results from the Spider scenario (see clause 5.3.2.3.3) as this represents a scenario with (artificial) very high channel loads that best allows for the analysis of different DCC and radio configurations.

It has to be noted that for most of the diagrams shown in the following, no difference between the two generation rules assessed in clause 5.5.1 can be observed. This intended behaviour results from the setup of the simulation scenario. As detailed in clause 5.3.2.3.3, vehicles driving in the Spider scenario exhibit dynamics that cause the generation rules of the CPM to always be triggered (the speed threshold for when to include an object is always met). This effect is depicted in Figure 31 for both the resulting message size and the number of objects included in every transmitted message for the static and dynamic message generation rules. As depicted, the difference for these two generation rules are minor in this scenario, with differences only resulting from different initialization times of the object inclusion determination algorithm.

Clause 5.5.2.2 details the effect of DCC on the operations of the CP Service. The effect of transmitting another cyclically generated message next to the CAM using ITS-G5 is detailed in clause 5.5.2.3.



(a) Average message size as a result of utilizing the static and dynamic message generation rules

(b) Boxplot for the total number of objects included in every transmitted message

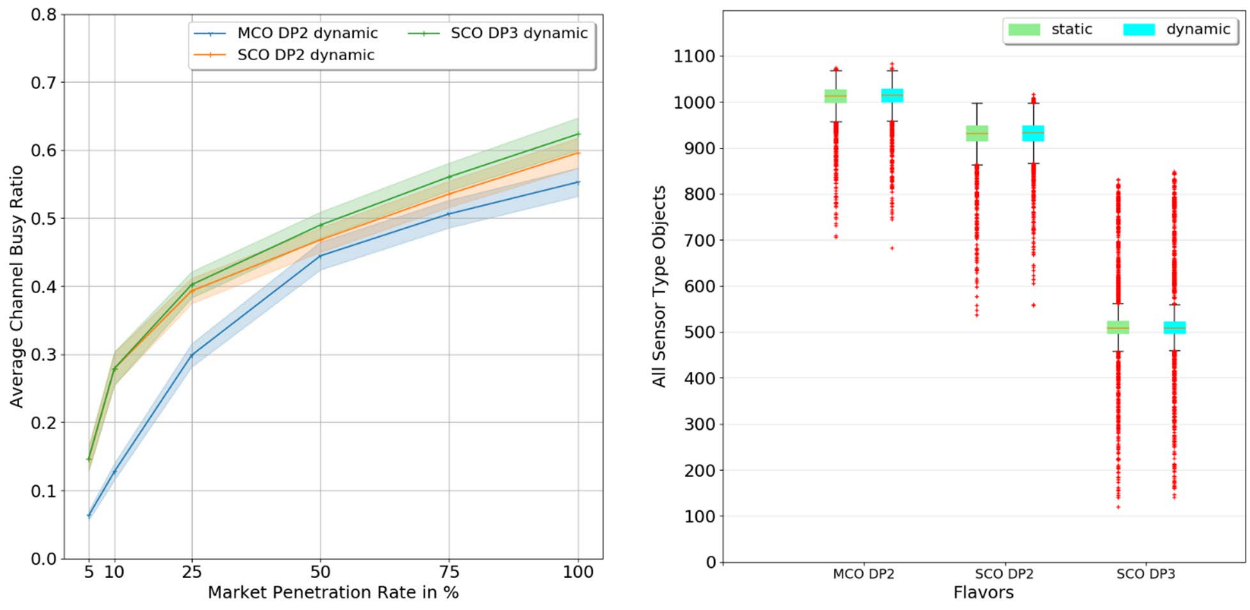
Figure 31: Comparison between the static and dynamic generation rules for the Spider Scenario at 100 % market penetration rate (S1)

5.5.2.2 Effect of DCC operations on the CP Service

It is expected that the observed channel utilization increases with an increasing number of communication enabled vehicles in the scenario. Alternatively, reducing the total number of messages transmitted in the same communication channel also reduces the expected observed channel load. For the three different transmission configurations outlined above, it is therefore expected that - regardless of the market penetration rate - the lowest channel load results from the MCO variant, in which each disseminated message, the CAM and the CPM, utilize a dedicated channel.

Figure 32 (a) depicts the recorded average Channel Busy Ratio (with standard deviation) for different market penetration rates and transmission configurations as measured by a passive network node for the respective channel utilized by the CPM. The passive probe is located in the centre of the scenario. For low market penetration rates, the observed channel utilization matches the intuitive expectation when comparing the two SCO variants with the MCO variant. At a market penetration rate of 10 %, for example, the observed Channel Busy Ratio for the two SCO variants is at around 26 %, whereas the MCO variant results in a channel load of about 13 %. With increasing market penetration rate, however, this changes dramatically: As soon as the average Channel Busy Ratio generated by the messages disseminated in the channel exceeds 40 %, DCC operations reduce the message budget available for each node. As a result, even at a market penetration rate of 25 %, the CPM is able to generate a channel load of about 30 % on its own (see MCO variant in Figure 32 (a)). For the SCO variants, however, in which CAMs and CPMs are transmitted on the same channel, DCC operations limit message transmission, severely reducing the resulting channel load at the expense of message dropping. This effect is even more prominent for very high market penetration rates, for which the CPM alone is able to generate sufficient load for the communication stack to enter DCC *Active 3*/*Restricted* mode (above 49 % Channel Busy Ratio) - which is accompanied with a dramatic reduction in available message transmission budgets.

The effect of DCC operations limiting the effectiveness of the concept of Collective Perception at higher channel utilization is also depicted in Figure 32 (b). The diagram shows the total number of objects each vehicle is currently aware of (i.e. a receiving vehicle is aware of another vehicle's presence) regardless of the sensor type at 100 % market penetration rate. Only unique vehicles are counted - vehicles detected by multiple sources (e.g. a particular vehicle is received by both CAM and CPM) are counted only once. It can be inferred that the MCO variant outperforms the SCO variants in terms of generated awareness, since vehicles are aware of most other traffic participants in this case. Closely following is the SCO DP2 configuration, in which CAMs and CPMs are transmitted with the same priority. A significantly reduced awareness by about 50 % is observed for the SCO DP3 scenario. The latter scenario, however, also results in the highest channel load, as depicted in Figure 32 (a). A detailed explanation for this behaviour is given in clause 5.5.2.3. From these findings, however, it can be concluded that transmission of the CPM is preferred on a separate ITS G5 communication channel to reduce the resulting channel load on each channel. This is even more important, when considering mixed market penetration rates, in which only some of the vehicles are able to receive the CPM. While this would be acceptable for messages that are not sent out frequently, the effectively used bandwidth is reduced for ITS-Ss not able to decode the CPM or any other cyclically disseminated message ("Day-1" ITS-Ss).



(a) Average Channel Busy Ratio (μ±σ) for different market penetration rates and transmission configurations on the channel utilized by the CPM (Spider scenario, Dynamic Message Generation Rules)

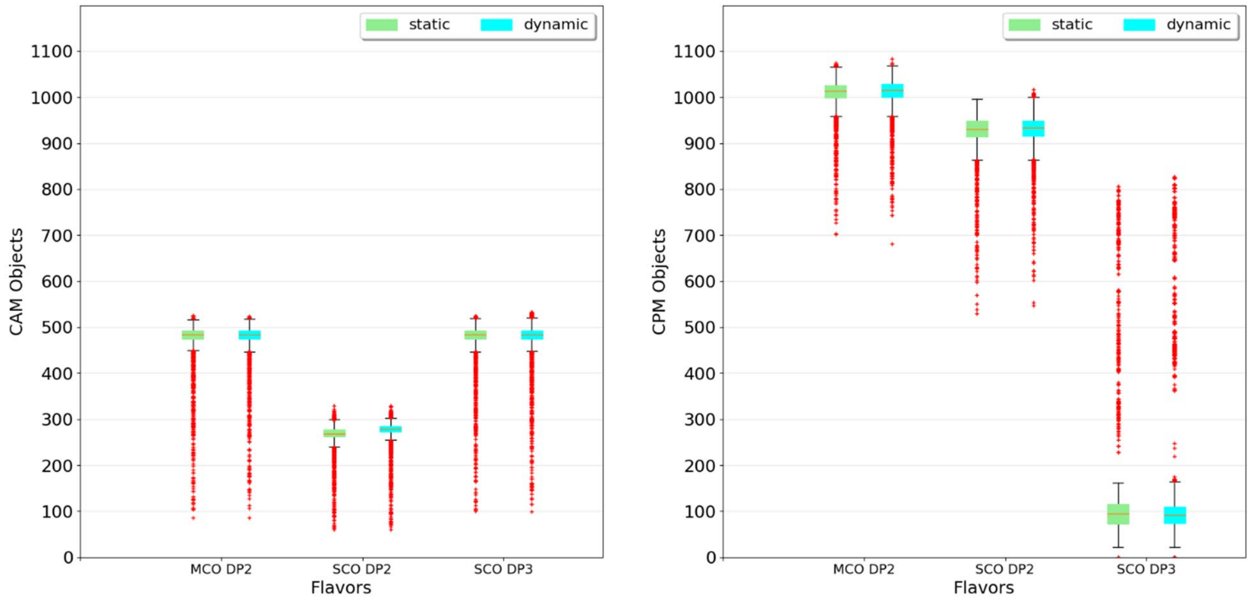
(b) Boxplots for total number of known objects by each communicating vehicle (no duplicates) over a sliding window of 1 000 ms for all sensor types (Radar, CAM, CPM) and different transmission configurations (Spider Scenario, 100 % market penetration rate)

Figure 32: Effect of DCC operations on Channel Utilization and Generated Awareness (S1)

5.5.2.3 Effect of CP Service operation on other (prospective) ITS Messages

Clause 5.5.2.2 outlined that dissemination of CP Messages is preferred to occur on a channel other than the CCH which is used for CAM transmission to effectively increase awareness of receiving ITS-Ss. By analysing which contribution to an ITS-S's awareness is made by each available information source (CAM, CPM), it can be derived that disseminating any additional cyclically generated message faces the same challenges as the CPM, if transmitted alongside the CAM on the same channel.

Figure 33 (a) depicts the awareness generated by receiving CA Messages for the three different transmission configurations at a market penetration rate of 100 %. For the setup chosen for this simulation, the reception of CA Messages results in a median of about 480 known vehicles in the case of CA and CP Messages both using their own channel for dissemination (compare to MCO DP2 variant). This particular configuration can be considered the baseline, as the transmission of each respective message is not influenced by the other message in terms of competing for channel access. Since the CAM needs to be transmitted with a DCC priority of DP2 [i.7], it is expected that the SCO DP3 variant, in which the CPM is transmitted at a lower priority compared to the CAM, yields similar performance compared to the MCO DP2 variant, as depicted. A somewhat unexpected finding is the observed awareness resulting from transmitting both the CAM and the CPM with the same DCC priority DP2: For this configuration, generated awareness is almost halved, with only a median of about 280 known vehicles as a result of CAM reception. This is the result of the implementation of the DCC queue, which is following the first-in, first-out paradigm and is assigned a length of 1 (i.e. only one message can be placed in the DCC queue at a time). Whenever a message is encoded by a particular Facility layer service (CA-, CP-Service), the generated message payload is placed into one of the DCC queues mapped to the requested message priority. In the case of sending both the CA and CP Message with the same DCC priority DP2, whichever message is placed into the corresponding DCC queue last, has a higher probability of being transmitted. Since messages placed into the DCC queue are not immediately passed on to a corresponding Enhanced Distributed Channel Access (EDCA) queue, but rather based on the availability of channel resources, any further message placed into the DCC queue will replace an existing message. It should be noted that this is implementation-specific and may exhibit a different behaviour for different stack implementations.



(a) Awareness generated by receiving CA Messages only

(b) Awareness generated by receiving CP Messages only

Figure 33: Boxplots for total number of known objects by each communicating vehicle (no duplicates) over a sliding window of 1 000 ms for indicated message type and different transmission configurations (Spider Scenario, 100 % market penetration rate, S1)

This observation is also apparent in Figure 33 (b), depicting the number of objects reported as a result of CPM reception with respect to the three different transmission configurations at a market penetration rate of 100 %. The capability of CPM transmission can be derived from the MCO DP2 variant: A median of about 1 050 other vehicles are known to each other vehicle as a result of only receiving CPMs. This represents the highest achievable awareness for this message type, since both message types utilize their own transmission channel. For the SCO DP3 variant, CAMs are favoured by the communication stack over CPMs, resulting in seldom CPM transmission and therefore a significantly reduced awareness at only about a median of 100 known vehicles. For the SCO DP2 configuration, as described above, the CPM is favoured over the CAM for transmission as a result of the stack implementation.

As depicted in Figure 32 (a), these simulations were performed close to the maximum allowed channel load of about 65 %, with most vehicles operating in either the *Active 3* or *Relaxed* state of the DCC state machine. This severely limits the message budget available to the ITS-Ss. The observed behaviour will be more relaxed in scenarios with reduced channel load, however. The key finding is that DCC operations, its specific implementation and message priority has a significant impact not only on the CPM, but on any other ITS message that needs to be send cyclically alongside the CAM: Especially in scenarios of increased channel load, messages that are sent alongside the CAM at a similar priority need to be offloaded to a separate ITS channel.

5.5.2.4 Summary

The high-load Spider-scenario allows for the analysis of the behaviour of the CP service at a channel utilization close to the allowed limit by DCC of 65 %. It is shown that for lower market penetration rates of up to about 10 % (for the Spider Scenario), transmitting an additional message cyclically alongside the CAM in the same channel with a similar transmission characteristic compared to the CAM results in about twice the channel load compared to a CAM-only scenario. With increasing market penetration rate, more vehicles are competing for channel access, thereby increasing the observed channel load disproportionally. As a result, DCC operations limit the available message budget for each ITS-S, resulting in degraded performance of the CP Service in case of the CPM being sent as a lower priority message compared to the CAM. Especially for high-load scenarios, transmission of the CPM is thereby favoured on a separate channel.

This finding can be generalized for any other additional ITS message that needs to be sent cyclically alongside the CAM. Current standardization does not foresee sending another message than the CAM as DP2. Any further message therefore needs to employ lower priority levels - thereby increasing the chance of the message being dropped with increasing load.

5.5.3 Message Segmentation

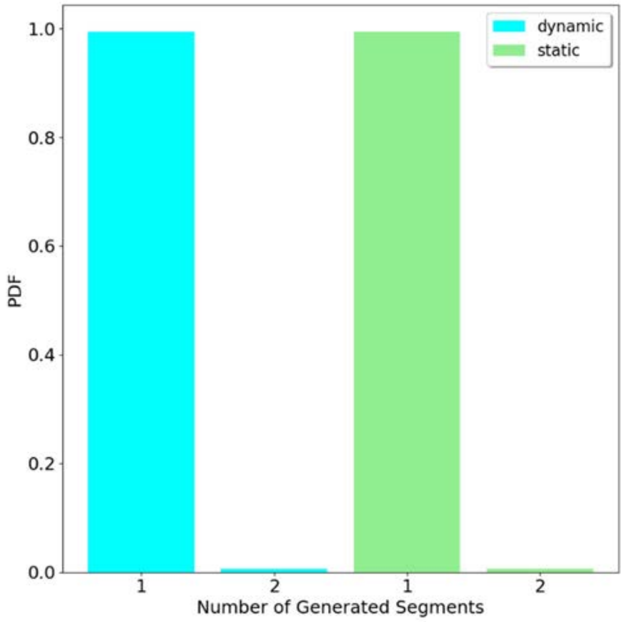


Figure 34: Generated CP Message segments in the Spider scenario at 100 % market penetration rate (S1)

In situations where there are lots of perceived objects, CPMs can theoretically grow quite large. For that case, clause 4.3 includes rules for message segmentation. However, Figure 34 shows that even in the artificial, high-load scenario with 100 % market penetration, segmentation is required only very rarely. In the Luxemburg scenario, there was not a single message that had to be segmented. Nevertheless, segmentation support should become important in the future, with more refined sensor systems, able to perceive lots of pedestrians.

6 CP Message Format and Data Elements

6.1 General Structure of a CPM PDU

A CPM is composed of one common ITS PDU header and multiple containers, which together constitute a CPM.

The general structure of a CPM is illustrated in Figure 35.

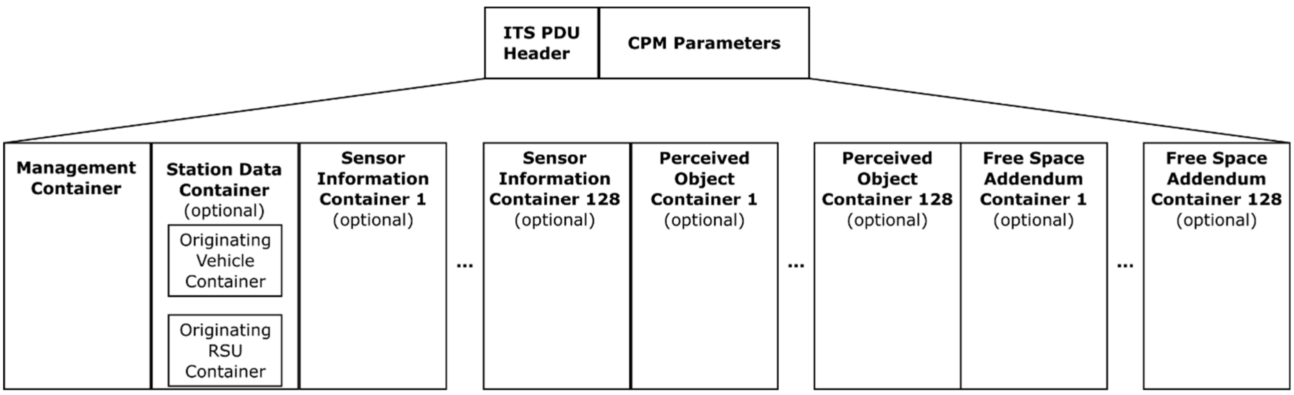


Figure 35: General Structure of a CPM

The ITS PDU header is a common header that includes the information of the protocol version, the message type and the ITS-S ID of the originating ITS-S.

Regardless of which type of ITS-S disseminates a CPM, the Management Container provides information regarding the Station Type and the Reference Position of the ITS-S.

The message can be disseminated either by a moving ITS-S, such as a vehicle, or by a stationary ITS-S, such as a RSU.

In case of a CPM generated by a vehicle, the Station Data Container contains the dynamic information of the originating ITS-S. For moving ITS-S, the Station Data Container data is mandatory.

In case of a CPM generated by a RSU, the Originating RSU Container may provide references to identification numbers provided by the MAP Message [i.5] disseminated be the same RSU. These references are required in order to match data provided by the CPM to the geometry of an intersection or road segment as provided by the MAP message. It is not required that a RSU transmits a MAP message for matching objects to road geometries. In this case, the Station Data Container should be omitted. It is for this reason that the Station Data Container is set as optional.

The Sensor Information Container represents an option to also provide information about the sensory capabilities of an ITS-S. Depending on the station type of the originating ITS-S, different container descriptions are available to encode the properties of a sensor. The Sensor Information Containers are attached at a lower frequency than the other containers, as defined in clause 4.3.

A Perceived Object Container can be added for every object that has been perceived by an ITS-S. It provides information about the detected object with respect to the disseminating station. Classifications and positions matched to road data can also be provided. This container type is only added if objects have been detected according to the inclusion rules defined in clause 4.3.

The Free Space Addendum Container can be added to describe changes to a computed free space description.

Each container is composed of a sequence of optional or mandatory Data Elements (DEs) and/or Data Frames (DFs). DEs and DFs are mandatory unless specified otherwise. The present document provides CPM content proposals for vehicle and RSU ITS-Ss.

6.2 ITS PDU header

The ITS PDU header should be included as specified in ETSI TS 102 894-2 [i.4]. Detailed data presentation rules of the ITS PDU header in the context of a CPM should be as specified in annex B and annex C.

6.3 Management Container

The management container provides basic information about the originating ITS-S, regardless of whether it is a vehicle or RSU type station. The container includes the station type, reference position and optionally information about the current message segment as part of the *perceivedObjectContainerSegmentInfo*. Message segmentation should be managed according to clause 4.3.6. The reference position is used for referencing objects relative to a provided global position. The reference point to be provided is detailed in ETSI EN 302 890-2 [i.17].

NOTE 1: For vehicles, the reference point refers to the ground position of the centre of the front side of the bounding box of the vehicle.

NOTE 2: For RSUs, the reference point refers to an arbitrary position on a road segment or intersection. This point is used to determine the offset to other data points, as detailed in CEN ISO/TS 19091 [i.5].

The *perceivedObjectContainerSegmentInfo* is only present in case the message is segmented. This DF indicates the current segment number with respect to the total number of generated message segments. Each CPM segment can be decoded and interpreted without the need to receive and process all message segments, as specified in clause 4.3.6.

The total number of perceived objects should be provided in the variable *numberOfPerceivedObjects*. Due to the message generation rule and the associated object inclusion scheme, the number of reported objects does not have to match up with the number of included objects of a received CPM.

NOTE 3: A receiving ITS-S should therefore not assume that the received *PerceivedObjects* in the perceived object container represents all objects known to the transmitter. A receiver needs to listen for further CPMs from the same transmitter for at least one second until all objects have been received.

6.4 Station Data Container

6.4.1 Introduction

The optional Station Data Container provides more specific information about the originating ITS station in addition to the common information provided by the Management Container. This frame distinguishes two cases with respect to the disseminating ITS-S type. The originating station can be a vehicle with attributes listed in the Originating Vehicle Container or a RSU with parameters presented in the Originating RSU Container.

6.4.2 Originating Vehicle Container

The Originating Vehicle Container comprises information about the dynamics of the vehicle disseminating the CPM. It should be included in every CPM transmitted by a vehicle originating station ITS-S.

Such information is required to transform objects described in the Perceived Object Container of the same CPM into a target reference frame, such as a vehicle centred coordinate system as detailed in Figure 36 [i.2].

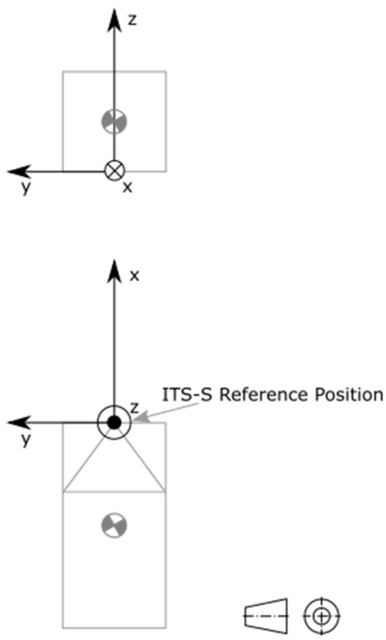


Figure 36: Coordinate system to be used for vehicle as disseminating ITS-S

The Originating Vehicle Container provides information which seem to a certain extent redundant to the Basic Vehicle Container High Frequency included in a CA message [i.7] which will also be transmitted by the same ITS-S. It is assumed that an ITS-S receiving a CPM from the originating station also receives a CAM from the same ITS-S. However, due to the delay between the reception of a CPM and a previous CAM, vehicle dynamics variables need to be extrapolated, which comes at the cost of increasing the inaccuracy of successive coordination transformation processes. Furthermore, the Originating Vehicle Container provides additional parameters which are not provided by the CA message. These optional parameters are the Vehicle Orientation Angle, Pitch Angle, Roll Angle, Vehicle Height and Trailer Data. Those parameters are used for providing the actual geometric dimensions of the originating ITS-S, optionally in a three-dimensional fashion (Roll, yaw, pitch) which are not provided by the CA message. The Vehicle Orientation Angle provides means to transmit the actual orientation of the vehicle opposed to the vehicle heading which references the orientation of the provided velocity vector magnitude only, as depicted in Figure 37. The dimensions of the disseminating vehicle (height, length, width) may optionally be provided, e.g. in case a CAM is not transmitted in parallel.

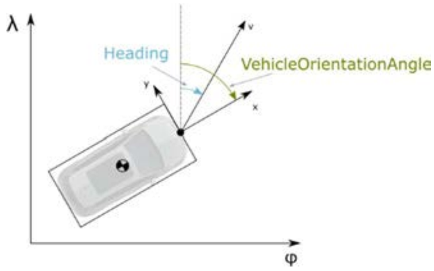


Figure 37: Vehicle Orientation Angle

The container also provides means to include a description for trailers attached to a towing vehicle, e.g. for trucks. Different layouts for attached trailers are possible. Providing the *TrailerData* is required in order to transform objects detected by a sensor mounted to a trailer into a receiving ITS-S's reference frame. Figure 38 depicts several possible layouts. Every trailer added to the description of a vehicle consists of a *TrailerData* container which can be added up to two times, e.g. to describe layouts such as the ones depicted in Figure 38 (c) and (d). Each *TrailerData* provides a new reference point ID, incrementing from 1. The reference point ID 0 always refers to the reference point of the towing vehicle. An offset to a hitch point in the longitudinal direction according to ISO 8855 [i.2] from the towing vehicle's reference point is provided. The trailer's dimensions are provided by defining the trailer's front and rear overhang with respect to the trailer's hitch point, as depicted. The width of the trailer may be provided optionally. The hitch angle is also optionally available. More configurations for providing reference points for ITS-S can be found in ETSI EN 302 890-2 [i.17].

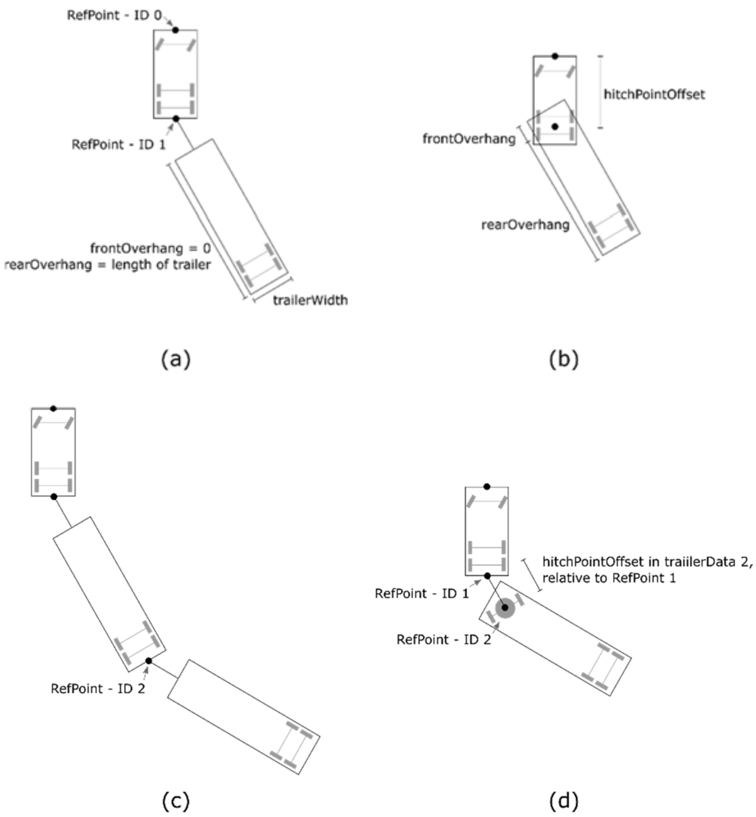


Figure 38: Describing the setup of trailers attached to a towing vehicle in the CPM

6.4.3 Originating RSU Container

In case the originating ITS-S is a RSU, the Station Data Container contains the Originating RSU Container, which includes two parameters to reference information received by the MAP message [i.5]. Both, the *IntersectionReferenceID* and *RoadSegmentID* are optional parameters that can be used to refer to the road infrastructure provided by the road lane topology service. It is therefore required for the RSU to also transmit a MAP message which is referenced by the CPM either of the two variables stated before. In case of RSUs disseminating the CPM, the reference position should refer to the reference position as defined in CEN ISO/TS 19091 [i.5], e.g. an arbitrary point on the intersection, as depicted in Figure 39.

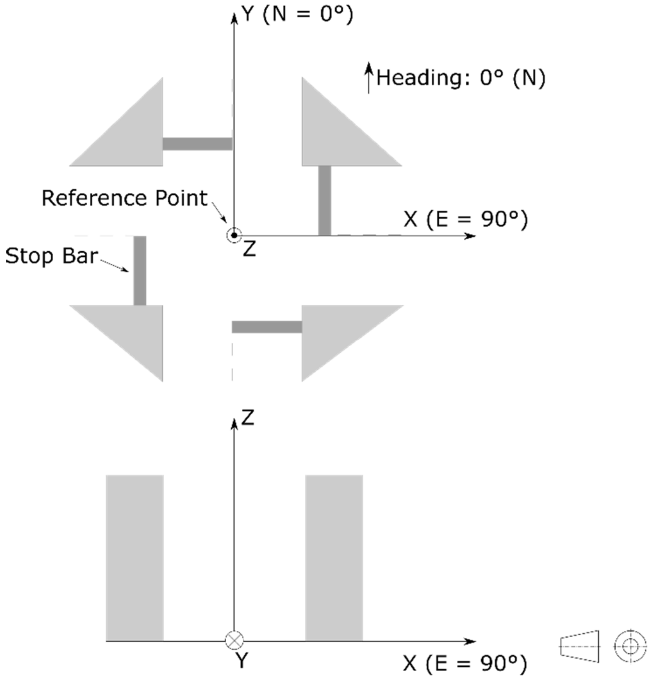


Figure 39: Coordinate System to be used for RSU as disseminating ITS-S

6.5 Sensor Information Container

The sensor information container lists information for individual sensor(s) which are mounted to a a vehicle or roadside unit to detect surrounding objects.

This container type offers the possibility to provide descriptive information about the sensory properties of a disseminating ITS-S. Every described sensor is provided with a pseudonym id which is in turn utilized in the *Perceived Object Container* to relate measured object information to a particular sensor. Additionally, each provided sensor information DF is accompanied by a sensor categorization to indicate the type of the perception system. This can be a specific sensor type such as a radar or lidar sensor up to a system providing fused object information from multiple sensors. As different sensor types may be attached to an ITS-S, e.g. radar, LIDAR, combined sensor fusion system and alike, this container provides different possibilities for describing the properties of a sensor-system.

Two types of descriptions are differentiated: sensors which are mounted to moving station, such as vehicles, are described using the *vehicleSensor* description DF. Sensors which are stationary, e.g. because they are mounted to a RSU, are described by using a *stationarySensor* variant DF. The perception area of a perception system can be inferred on the receiving ITS-S by the data provided in the *SensorInformationContainer.*

Either variant can be used to describe the sensory capabilities of the disseminating ITS-S. This can be the actual parameters of a perception-system, i.e. its actual perception range, or the applicable perception area of the perception system, i.e. the area in which objects will be detected by the perception system.

By providing sensor information as part of the CP message, receivers are given the opportunity to derive the surrounding areas which are currently covered by at least one perception system.

A *vehicleSensor* type description provides information about sensors mounted to vehicles. The properties of these perception systems are defined by providing the mounting position of a sensor with respect to a specific reference point on the vehicle. The range and horizontal as well as optional vertical opening angles are provided to describe the sensor's frustum. In case a sensor has multiple detection areas, such as a combined long- and mid-range sensor, up to ten perception areas for a sensor can be encoded. The provided offset from a reference point on the vehicle serves as the origin of a sensor-specific local Cartesian coordinate system. Figure 40 illustrates the information provided by this container type.

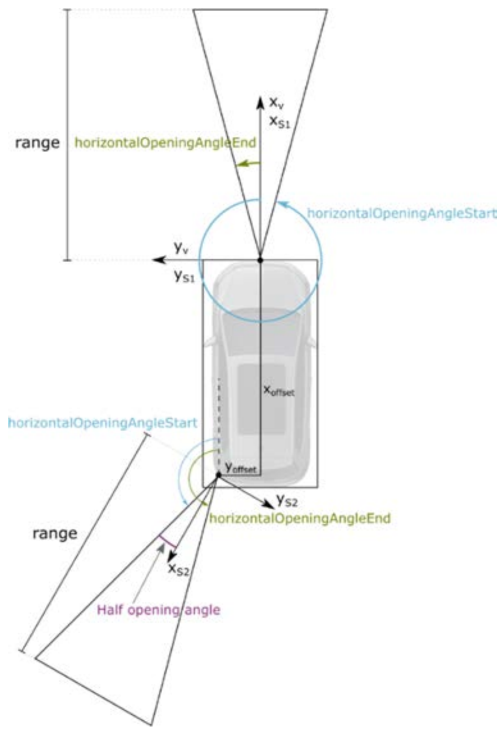


Figure 40: Information provided by *VehicleSensor* type

In case of a perception system mounted to a RSU, the *stationarySensorRadial* DF provides a similar concept to describe the system's perception capabilities. The position provided by the offset from a reference point on the vehicle also serves as the origin of a sensor-specific local Cartesian coordinate system. Being provided with the sensor position and the opening angles (see Figure 40 and Figure 41), the receivers of the CPM can determine the sensor measurement area by projecting the area defined by the opening angles on the ground.

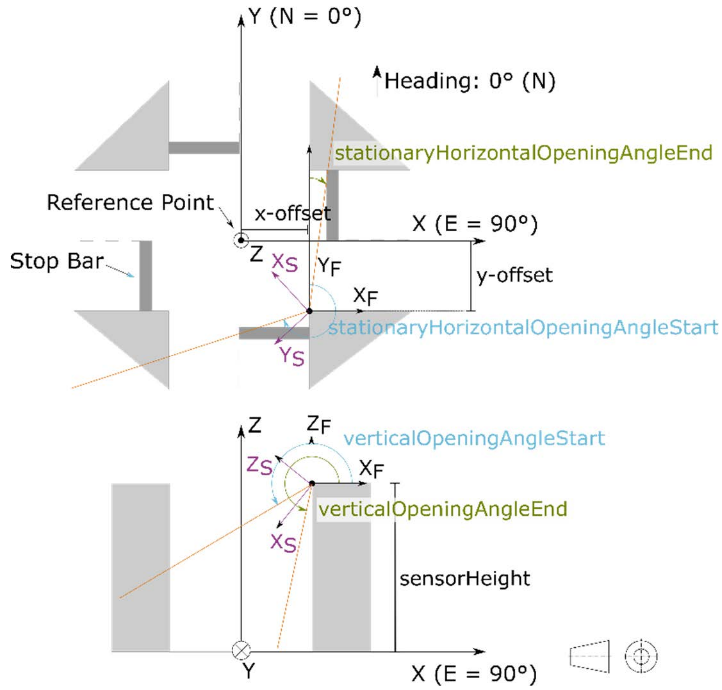


Figure 41: Information provided by the StationarySensorRadial type

For stationary sensors, alternative DFs for describing the perception system's perceived area are provided in case the origin of a sensor system should or cannot be revealed. This is particularly useful if the perception area is generated by combining several separate systems which however act as one sensor. As illustrated in Figure 42, a geographical representation of a system's perception area can be expressed in terms of a circular, rectangular, ellipsoidal or a polygon area. Due to their geographical reference of the reference point, these types are applicable to stationary sensors only.

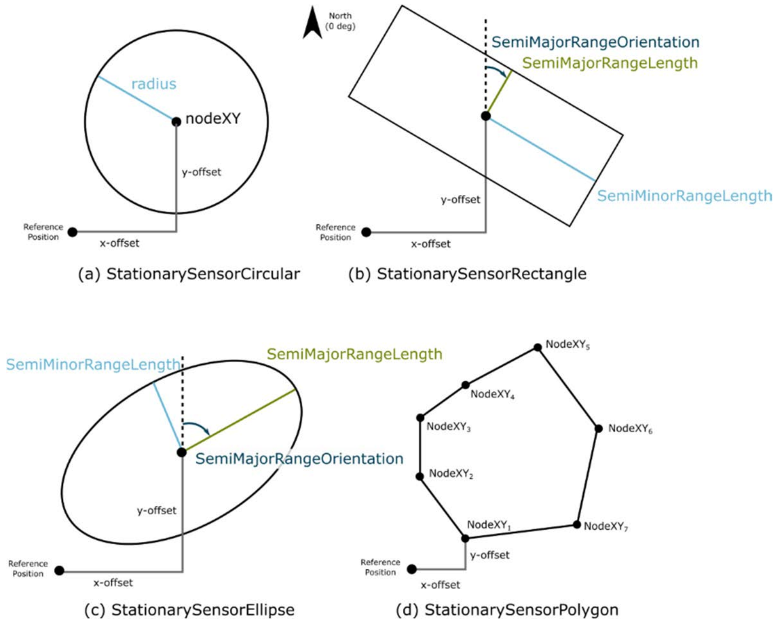


Figure 42: Description types for perception area of stationary sensors

The optional *FreeSpaceConfidence* DE can be used to provide information that a particular sensor is able to provide confirmed measurement about detected free space. The indication states an isotropic confidence level that can be assumed for the entire detection area. *FreeSpaceConfidence* should be used to indicate the corresponding confidence as specified in clause 4.4.2.

In combination with received objects, a receiver can employ the free space confidence indication to compute the resulting free space by applying a simple ray-tracing algorithm. Figure 43 depicts a corresponding scenario. The depicted perception area can be assumed to be free with an isotropic *FreeSpaceConfidence* (blue area), generated by the *DetectionArea* DF. For each object detected by a transmitter, the receiver is able to compute the resulting non-free and shadowed areas for which no or insufficient measurement areas are available.

NOTE: Not all objects known to a transmitter will be reported in every CPM. The receiver therefore needs to ensure that suitable tracking and prediction mechanisms for previously transmitted objects are employed to update the shadowed area accordingly.

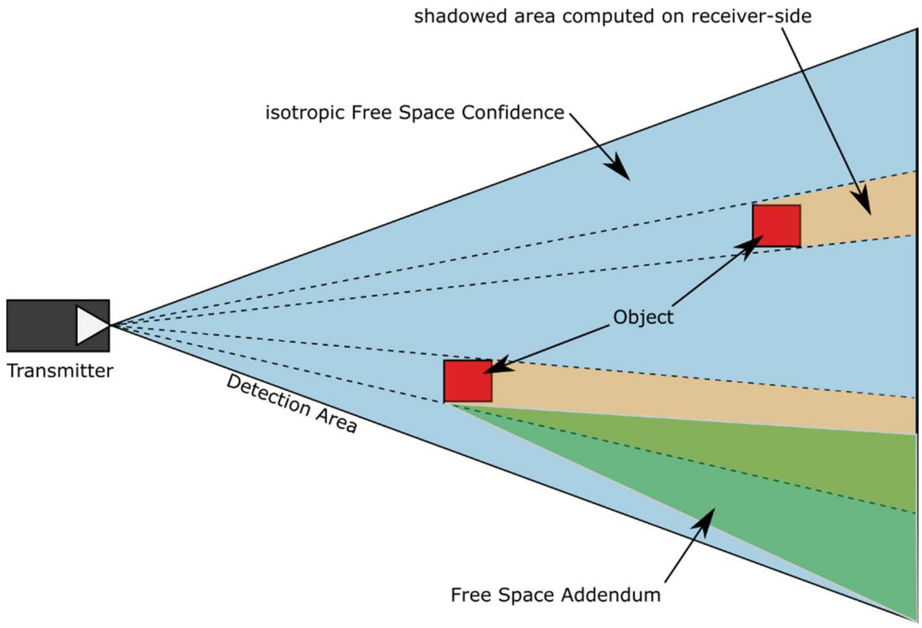


Figure 43: Computed Free Space from the perspective of a receiving ITS-S

The received geometric extension of a *PerceivedObject* should be used to compute the resulting shadowed area for each object. For this purpose, a simple ray-tracing like approach can be utilized. A ray thereby connects from the origin of a particular sensor to the outermost corner-points of the received object geometry and extends to the perception range of a particular sensor. The area behind the object from the perspective of the sensor mounting point is considered as shadowed, as visualized in Figure 43. No indication about the free space confidence can be given behind a shadowing object. A description in three dimensions may be applied, as depicted in Figure 45. In case an object is detected by a sensor with a certain height above ground (e.g. a signage gantry), the same ray-tracing like approach can be employed for a three-dimensional representation.

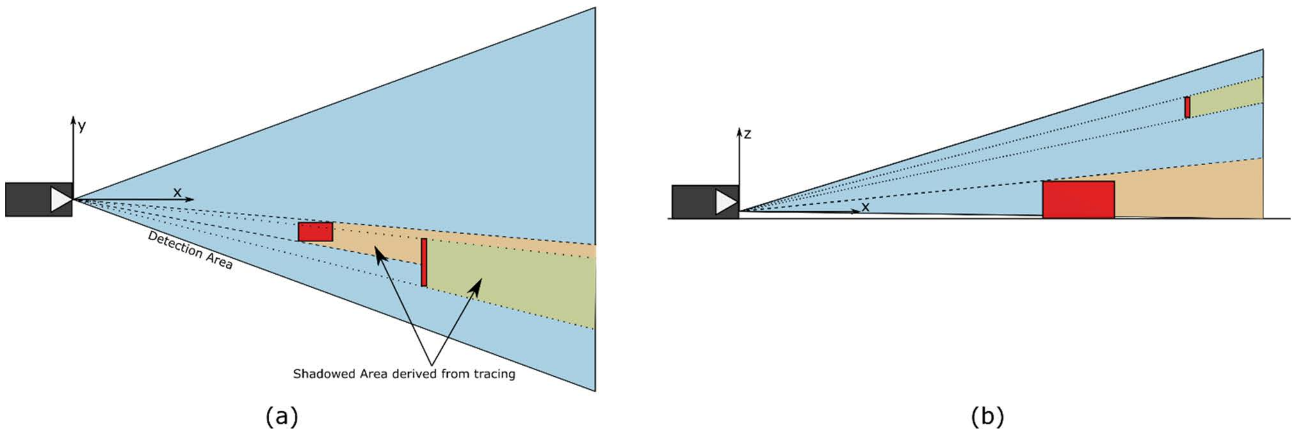


Figure 44: Three dimensional representation of a derived free space description

The transmitting ITS-S of a CPM is able to compute the expected shadowing model from the perspective of a receiving ITS-S. In case the shadowing model does not apply, e.g. as a result of specific sensor properties, or if the area of confirmed free space does not cover the complete detection area, a *FreeSpaceAddendumContainer* DF can be added to the CPM, as detailed in clause 6.7 and depicted in Figure 43.

6.6 Perceived Object Container

Whenever an object is detected by a disseminating ITS-S according to the definition provided in clause 4.3, a Perceived Object Container should be added to the CPM. The container enables a detailed description of the dynamic state and properties of a detected object. The information regarding the location and dynamic state of the perceived object are provided in a coordinate system as specified by ISO 8855 [i.2] and depicted in Figure 36.

Figure 36 also depicts the coordinate system that should be used for the description of the object's state variables in case of a vehicle sharing information about a detected object,

In case of RSUs disseminating the CPM, the reference position should refer to the reference position as defined in CEN ISO/TS 19091 [i.5], e.g. an arbitrary point on the intersection, as depicted in Figure 39.

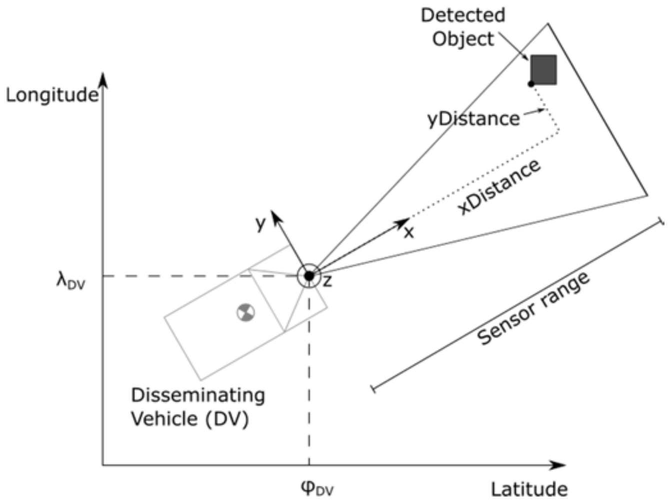


Figure 45: Coordinate System for detected object for vehicle as disseminating ITS-S

Every object is described by at least providing the distance and speed in the x/y plane of the respective coordinate system with respect to a station's reference point, as depicted in Figure 45 for the case of a vehicle as disseminating ITS-S. The reference point of a measurement is also provided as part of the message.

Furthermore, an *objectID* is assigned to each detected object. This ID is taken from a range of monotonously increasing numbers and is maintained per object, as long as an object is perceived and new sensor measurements are assigned to the object. The range of allowed *objectIDs* is between 0 and 255. As soon as *objectID* 255 has been assigned to an object, the next object gets assigned ID 0 in a round-robin fashion.

A time of measurement is provided for each object which is the time difference for the provided measurement information with respect to the generation delta time stated in the management container. Figure 46 provides an interpretation for the time of measurement which is always relative to the *GenerationDeltaTime* encoded in the message and the timestamp which corresponds to when the state space information about a detected object is made available. The *GenerationDeltaTime* always corresponds to the latest point in time when the latest reference position is available on the transmitting side. Upon receiving the message, the receiver will compute its own local *GenerationDeltaTime* based on its current absolute timestamp. The difference between the encoded *GenerationDeltaTime* in the received CPM and the local *GenerationDeltaTime* then represents the age of the CPM. The received encoded Time of Measurements then needs to be added to the age of the CPM to compute the age of the encoded object. Positive Time of Measurements thereby indicate that the Time of Measurement needs to be added to the message age on the receiver side, as the state space of the object has been created before the transmitter's *GenerationDeltaTime* and is therefore older. Negative time values indicate that the time of measurement needs to be subtracted from the age of the CPM as the state space of the described object has been determined after the transmitter's *GenerationDeltaTime* has been created. The Time of Measurement may therefore include any processing time of a sensor or data fusion system. In case the fused object state information is transmitted, the time of measurement should reference the point in time to which the state space has been predicted.

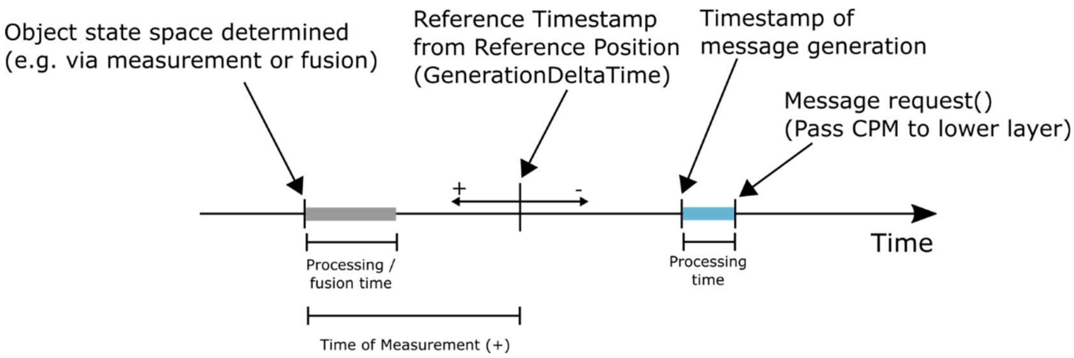


Figure 46: Transmitter-side for computing Time of Measurement

Several optional fields are available, to provide a more detailed description of a perceived object. Distance, Speed and Acceleration values can be provided in three dimensions along with the yaw angle of the object. Furthermore, a three-dimensional description of an object's geometric extension can be provided. A RSU is also able to provide a map-matching result for a particular object with respect to the MAP information.

The classification of each object is an optional field and allows for multi-dimensional classification and confidences. Each class may be detailed by providing applicable subclasses for each object with subclass confidences.

Detailed data presentation rules of the Perceived Object Container in the context of a CPM should be as specified in annex B.

6.7 Free Space Addendum Container

The Free Space Addendum Container can be attached to express different confidence levels for certain areas within the *DetectionArea* of a particular sensor. This container only needs to be added if the confidence indication needs to be altered with respect to the isotropic confidence level indication provided in the *SensorInformationContainer*. As such, the Free Space Addendum Container can be interpreted even if a received CPM does not contain the *SensorInformationContainer*. This can be the case when a sensor cannot utilize its entire *DetectionArea* to reliably provide a free space indication, or in case the shadowing model detailed in clause 6.5 does not apply for a particular object (e.g. in case of a radar sensor measuring two vehicles driving behind each other).

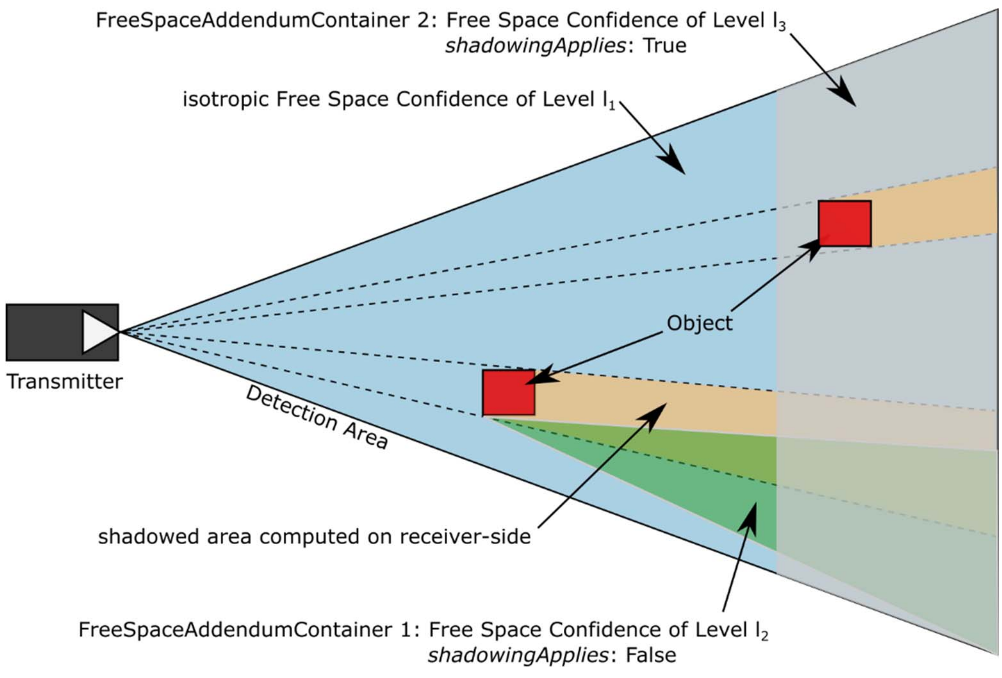


Figure 47: Free Space Addendum to indicate different levels of free space confidence

Figure 47 depicts two possible applications of the free space addendum container: The isotropic free space confidence provided in the *SensorInformationContainer* of level l_1 does not apply to the entire *DetectionArea* of the sensor. Instead, part of the computed shadowed area behind one of the object has a different free space confidence of level l_2 (e.g. as a result of sensor fusion processes). This area is described by providing a F*reeSpaceArea* DF as part of the *FreeSpaceAddendum* container. Additionally, the sensor system is only able to provide a free space confidence indication for a confined area within its *DetectionArea*. A different confidence level l_3 applies to the depicted grey area, expressed as an additional *FreeSpaceAddendum* container.

The *shadowingApplies* DE of the *FreeSpaceAddendum* container can be used to indicate if the simple tracing approach to compute the shadowed area behind objects also applies for the areas described in the *FreeSpaceAddendum* container.

In case of a transmitter also providing its own dimensions, the area occupied by the transmitting ITS-S should also be considered as occupied.

NOTE 1: Information about the geometric dimensions of a transmitting ITS-S may be provided in the CPM or additional transmitted messages such as the CAM.

The order of provided *FreeSpaceAddendum* containers for each sensor in a message is thereby overwriting the confidence level indication of an overlapping *FreeSpaceAddendum* container of the same sensor in an ascending fashion. In Figure 47, the grey confidence level indication l_3 overlaps the confidence levels l_1 (from the *SensorInformationContainer)* and l_2 (from the first *FreeSpaceAddendum* container) and therefore represents the dominating confidence level indication within the prescribed area.

A *FreeSpaceAddendumContainer* with confidence value of 0 may be located partially outside of the *detectionArea*.

NOTE 2: By providing a *FreeSpaceAddendum* container outside of the *detectionArea*, simpler shapes for the *FreeSpaceArea* may be leveraged to decrease the message size.

The mandatory *freeSpaceConfidence* DE of the *FreeSpaceAddendum* container expresses the free space confidence that applies to the area provided in the *freeSpaceArea* DF.

An optional list of *sensorIds* links to the corresponding *sensorInformationContainer* and may be provided to indicate which sensor provided the corresponding free space confidence indication.

6.8 CPM format and coding rules

6.8.1 Common data dictionary

The CPM format makes use of the common data dictionary as defined in ETSI TS 102 894-2 [i.4].

Where applicable, DEs and DFs that are not defined in the present document should be imported from the common data dictionary as specified in ETSI TS 102 894-2 [i.4].

NOTE: Detailed descriptions of all DEs and DFs in the context of CPM are presented in annex B of the present document.

6.8.2 CEN ISO/TS 19091 reference

The CPM format makes use of certain elements defined in the CEN ISO/TS 19091 [i.5].

Where applicable, DEs and DFs that are not defined in the present document should be imported from the CEN ISO/TS 19091 as specified in [i.5].

NOTE: Detailed descriptions of all DEs and DFs in the context of CPM are presented in annex B of the present document.

6.8.3 CPM data representation

The CPM format is specified in ASN.1.

Unaligned Packed Encoding Rules (PER) as defined in Recommendation ITU-T X.691/ISO/IEC 8825-2 [i.8] are used for CPM encoding.

The ASN.1 representation of the CPM is specified in the annex A of the present document.

Annex A: ASN.1 Proposal for CP Message syntax

This annex provides the ASN.1 syntax proposal of the Collective Perception Message (CPM).

NOTE 1: Some of the optional data elements and data frames conditions for the availability are specified in annex B.

NOTE 2: The ASN.1 proposal provided in the present document is informative only. The syntax may change considerably in a future normative document.

```
CPM-PDU-Descriptions {
itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) tr (103562) cpm (1) version
(1)
}

DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS
ItsPduHeader, Heading, ReferencePosition, Speed, DriveDirection, LongitudinalAcceleration,
LateralAcceleration, VerticalAcceleration, StationType, VehicleLength, VehicleWidth, YawRate,
SpeedConfidence
FROM ITS-Container {itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts
(102894) cdd (2) version (2) }

IntersectionReferenceID, LaneID, NodeOffsetPointXY, Offset-B10, Offset-B11, Offset-B12, Offset-
B13, Offset-B14,
Offset-B16, RoadSegmentReferenceID, VehicleHeight
FROM DSRC { iso (1) standard (0) signalizedIntersection (19091) profilec(2) dsrc (2) version2 (2)
}

GenerationDeltaTime
FROM CAM-PDU-Descriptions {itu-t(0) identified-organization(4) etsi(0) itsDomain(5) wg1(1)
en(302637) cam(2) version(2)} ;


--  The root data frame for collective perception message
CPM ::= SEQUENCE {
    header ItsPduHeader,
    cpm CollectivePerceptionMessage
}

CollectivePerceptionMessage ::= SEQUENCE {
    generationDeltaTime GenerationDeltaTime,
    cpmParameters       CpmParameters
}

CpmParameters ::= SEQUENCE {
    managementContainer                 CpmManagementContainer,
    stationDataContainer                StationDataContainer OPTIONAL,
    sensorInformationContainer          SensorInformationContainer OPTIONAL,
    perceivedObjectContainer            PerceivedObjectContainer OPTIONAL,
    freeSpaceAddendumContainer          FreeSpaceAddendumContainer OPTIONAL,
    numberOfPerceivedObjects            NumberOfPerceivedObjects,
    ...
}

CpmManagementContainer ::= SEQUENCE {
    stationType                          StationType,
    perceivedObjectContainerSegmentInfo     PerceivedObjectContainerSegmentInfo OPTIONAL,
    referencePosition                    ReferencePosition,
    ...
}

StationDataContainer ::= CHOICE {
    originatingVehicleContainer     OriginatingVehicleContainer,
    originatingRSUContainer         OriginatingRSUContainer,
    ...
}

OriginatingVehicleContainer ::= SEQUENCE {
    heading                     Heading,
```

```
    speed                       Speed,
    vehicleOrientationAngle     WGS84Angle OPTIONAL,
    driveDirection              DriveDirection DEFAULT forward,
    longitudinalAcceleration    LongitudinalAcceleration OPTIONAL,
    lateralAcceleration         LateralAcceleration OPTIONAL,
    verticalAcceleration        VerticalAcceleration OPTIONAL,
    yawRate                     YawRate OPTIONAL,
    pitchAngle                  CartesianAngle OPTIONAL,
    rollAngle                   CartesianAngle OPTIONAL,
    vehicleLength               VehicleLength OPTIONAL,
    vehicleWidth                VehicleWidth OPTIONAL,
    vehicleHeight               VehicleHeight OPTIONAL,
    trailerDataContainer        TrailerDataContainer OPTIONAL,
    ...
}

OriginatingRSUContainer ::= CHOICE {
    intersectionReferenceId     IntersectionReferenceID,
    roadSegmentReferenceId      RoadSegmentReferenceID,
    ...
}

SensorInformationContainer ::= SEQUENCE SIZE(1..128, ...) OF SensorInformation

SensorInformation ::= SEQUENCE {
    sensorID                Identifier,
    type                    SensorType,
    detectionArea           DetectionArea,
    freeSpaceConfidence     FreeSpaceConfidence OPTIONAL,
   ...
}

PerceivedObjectContainer ::= SEQUENCE SIZE(1..128, ...) OF PerceivedObject

PerceivedObject ::= SEQUENCE {
    objectID                Identifier,
    sensorIDList            SensorIdList OPTIONAL,
    timeOfMeasurement       TimeOfMeasurement,
    objectAge               ObjectAge OPTIONAL,
    objectConfidence        ObjectConfidence DEFAULT 0,
    xDistance               ObjectDistanceWithConfidence,
    yDistance               ObjectDistanceWithConfidence,
    zDistance               ObjectDistanceWithConfidence OPTIONAL,
    xSpeed                  SpeedExtended,
    ySpeed                  SpeedExtended,
    zSpeed                  SpeedExtended OPTIONAL,
    xAcceleration           LongitudinalAcceleration OPTIONAL,
    yAcceleration           LateralAcceleration OPTIONAL,
    zAcceleration           VerticalAcceleration OPTIONAL,
    yawAngle                CartesianAngle OPTIONAL,
    planarObjectDimension1  ObjectDimension OPTIONAL,
    planarObjectDimension2  ObjectDimension OPTIONAL,
    verticalObjectDimension ObjectDimension OPTIONAL,
    objectRefPoint          ObjectRefPoint DEFAULT 0,
    dynamicStatus           DynamicStatus OPTIONAL,
    classification          ObjectClassDescription OPTIONAL,
    matchedPosition         MatchedPosition OPTIONAL,
    ...
}

DetectionArea ::= CHOICE {
    vehicleSensor               VehicleSensor,
    stationarySensorRadial      AreaRadial,
    stationarySensorPolygon     AreaPolygon,
    stationarySensorCircular    AreaCircular,
    stationarySensorEllipse     AreaEllipse,
    stationarySensorRectangle   AreaRectangle,
    ...
}

VehicleSensor ::= SEQUENCE {
    refPointId                      RefPointId DEFAULT 0,
    xSensorOffset                   XSensorOffset,
    ySensorOffset                   YSensorOffset,
    zSensorOffset                   ZSensorOffset OPTIONAL,
    vehicleSensorPropertyList       VehicleSensorPropertyList,
    ...
}
```

```
VehicleSensorPropertyList ::= SEQUENCE SIZE(1..10) OF VehicleSensorProperties

VehicleSensorProperties ::= SEQUENCE {
    range                           Range,
    horizontalOpeningAngleStart     CartesianAngleValue,
    horizontalOpeningAngleEnd       CartesianAngleValue,
    verticalOpeningAngleStart       CartesianAngleValue OPTIONAL,
    verticalOpeningAngleEnd         CartesianAngleValue OPTIONAL,
    ...
}

AreaCircular ::= SEQUENCE {
    nodeCenterPoint      OffsetPoint OPTIONAL,
    radius               Radius
}

AreaEllipse  ::= SEQUENCE {
    nodeCenterPoint             OffsetPoint OPTIONAL,
    semiMinorRangeLength        SemiRangeLength,
    semiMajorRangeLength        SemiRangeLength,
    semiMajorRangeOrientation   WGS84AngleValue,
    semiHeight                  SemiRangeLength OPTIONAL
}

AreaRectangle ::= SEQUENCE {
    nodeCenterPoint             OffsetPoint OPTIONAL,
    semiMajorRangeLength        SemiRangeLength,
    semiMinorRangeLength        SemiRangeLength,
    semiMajorRangeOrientation   WGS84AngleValue,
    semiHeight                  SemiRangeLength OPTIONAL
}

AreaPolygon ::= SEQUENCE {
    polyPointList   PolyPointList
}

PolyPointList ::= SEQUENCE (SIZE(3..16, ...)) OF OffsetPoint

AreaRadial ::= SEQUENCE {
    range                                   Range,
    stationaryHorizontalOpeningAngleStart   WGS84AngleValue,
    stationaryHorizontalOpeningAngleEnd     WGS84AngleValue,
    verticalOpeningAngleStart               CartesianAngleValue OPTIONAL,
    verticalOpeningAngleEnd                 CartesianAngleValue OPTIONAL,
    sensorPositionOffset                    OffsetPoint OPTIONAL,
    sensorHeight                            SensorHeight OPTIONAL,
    ...
}

FreeSpaceAddendumContainer ::= SEQUENCE SIZE(1..128, ...) OF FreeSpaceAddendum

FreeSpaceAddendum ::= SEQUENCE {
    freeSpaceConfidence    FreeSpaceConfidence,
    freeSpaceArea          FreeSpaceArea,
    sensorIDList           SensorIdList OPTIONAL,
    shadowingApplies       ShadowingApplies DEFAULT TRUE,
    ...
}

FreeSpaceArea ::= CHOICE {
    freeSpacePolygon     AreaPolygon,
    freeSpaceCircular    AreaCircular,
    freeSpaceEllipse     AreaEllipse,
    freeSpaceRectangle   AreaRectangle,
    ...
}

ObjectDistanceWithConfidence ::= SEQUENCE {
    value        DistanceValue,
    confidence   DistanceConfidence
}

ObjectDimension ::= SEQUENCE {
    value       ObjectDimensionValue,
    confidence  ObjectDimensionConfidence
}
```

```
CartesianAngle ::= SEQUENCE {
    value       CartesianAngleValue,
    confidence  AngleConfidence
}

WGS84Angle ::= SEQUENCE {
    value       WGS84AngleValue,
    confidence  AngleConfidence
}

SpeedExtended ::= SEQUENCE {
    value       SpeedValueExtended,
    confidence  SpeedConfidence
}

SensorIdList ::= SEQUENCE SIZE(1..128, ...) OF Identifier

TrailerDataContainer ::= SEQUENCE SIZE(1..2) OF TrailerData

TrailerData ::= SEQUENCE {
    refPointId          RefPointId,
    hitchPointOffset    HitchPointOffset,
    frontOverhang       FrontOverhang,
    rearOverhang        RearOverhang,
    trailerWidth        VehicleWidth OPTIONAL,
    hitchAngle          CartesianAngle OPTIONAL,
    ...
}

LongitudinalLanePosition ::= SEQUENCE {
    longitudinalLanePositionValue        LongitudinalLanePositionValue,
    longitudinalLanePositionConfidence   LongitudinalLanePositionConfidence
}

MatchedPosition ::= SEQUENCE {
    laneID                      LaneID OPTIONAL,
    longitudinalLanePosition    LongitudinalLanePosition OPTIONAL,
    ...
}

PerceivedObjectContainerSegmentInfo ::= SEQUENCE {
    totalMsgSegments    SegmentCount,
    thisSegmentNum      SegmentCount
}

ObjectClassDescription ::= SEQUENCE (SIZE(1..8)) OF ObjectClass

ObjectClass ::= SEQUENCE {
    confidence  ClassConfidence,
    class    CHOICE {
        vehicle                 VehicleSubclass,
        person                  PersonSubclass,
        animal                  AnimalSubclass,
        other                   OtherSubclass
    }
}

VehicleSubclass ::= SEQUENCE {
    type        VehicleSubclassType DEFAULT 0,
    confidence  ClassConfidence DEFAULT 0
}

PersonSubclass ::= SEQUENCE {
    type        PersonSubclassType DEFAULT 0,
    confidence  ClassConfidence DEFAULT 0
}

AnimalSubclass ::= SEQUENCE {
    type        AnimalSubclassType DEFAULT 0,
    confidence  ClassConfidence DEFAULT 0
}

OtherSubclass ::= SEQUENCE {
    type        OtherSublassType DEFAULT 0,
    confidence  ClassConfidence DEFAULT 0
}

OffsetPoint ::= SEQUENCE{
```

```
    nodeOffsetPointxy   NodeOffsetPointXY (WITH COMPONENTS {..., node-LatLon ABSENT, regional 
ABSENT}),
    nodeOffsetPointZ    NodeOffsetPointZ OPTIONAL
}

NodeOffsetPointZ ::= CHOICE {
    node-Z1 Offset-B10, -- node is within 5.11m of last node
    node-Z2 Offset-B11, -- node is within 10.23m of last node
    node-Z3 Offset-B12, -- node is within 20.47m of last node
    node-Z4 Offset-B13, -- node is within 40.96m of last node
    node-Z5 Offset-B14, -- node is within 81.91m of last node
    node-Z6 Offset-B16  -- node is within 327.67m of last node
}

AnimalSubclassType        ::= INTEGER {unknown(0)} (0..255)

ClassConfidence           ::= INTEGER {unknown(0), onePercent(1), oneHundredPercent(100), 
unavailable(101)} (0..101)

WGS84AngleValue           ::= INTEGER {wgs84North(0), wgs84East(900), wgs84South(1800), 
wgs84West(2700), unavailable(3601)} (0..3601)

CartesianAngleValue       ::= INTEGER {zeroPointOneDegree(1), oneDegree(10), unavailable(3601)} 
(0..3601)

AngleConfidence           ::= INTEGER {zeroPointOneDegree (1), oneDegree (10), outOfRange(126), 
unavailable(127)} (1..127)

SemiRangeLength           ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..10000)

DistanceValue             ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100)} (-132768..132767)

DistanceConfidence        ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100), outOfRange(101), 
unavailable(102)} (0..102)

DynamicStatus             ::= INTEGER {dynamic(0), hasBeenDynamic(1), static(2)} (0..2)

HitchPointOffset          ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..100)

FrontOverhang             ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..50)

FreeSpaceConfidence        ::= INTEGER {unknown(0), onePercent(1), oneHundredPercent(100), 
unavailable(101)} (0..101)

LongitudinalLanePositionValue  ::= INTEGER {zeroPointOneMeter(1)} (0..32767)

LongitudinalLanePositionConfidence  ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100), 
outOfRange(101), unavailable(102)} (0..102)

ObjectAge                 ::= INTEGER {oneMiliSec(1)} (0..1500)

ObjectConfidence          ::= INTEGER {unknown(0), onePercent(1), oneHundredPercent(100), 
unavailable(101)} (0..101)

ObjectDimensionValue      ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..1023)

ObjectDimensionConfidence ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100), outOfRange(101), 
unavailable(102)} (0..102)

ObjectRefPoint            ::= INTEGER {mid(0), bottomLeft(1), midLeft(2), topLeft(3), 
bottomMid(4), topMid(5), bottomRight(6), midRight(7), topRight(8)} (0..8)

OtherSublassType          ::= INTEGER {unknown(0), roadSideUnit(1)} (0..255)

PersonSubclassType        ::= INTEGER {unknown(0), pedestrian(1), personInWheelchair(2), 
cyclist(3), personWithStroller(4), personOnSkates(5), personGroup(6)} (0..255)

Radius                    ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)}  (0..10000)

Range                     ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..10000)

RearOverhang              ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..150)

RefPointId                ::= INTEGER (0..255)

SensorHeight              ::= INTEGER  {zeroPointZeroOneMeter(1)} (-5000..5000)

ShadowingApplies          ::= BOOLEAN
```

```
Identifier                 ::= INTEGER (0..255)

NumberOfPerceivedObjects  ::= INTEGER (0..255)

SensorType                 ::= INTEGER {undefined(0), radar(1), lidar(2), monovideo(3),
stereovision(4), nightvision(5), ultrasonic(6), pmd(7), fusion(8), inductionloop(9),
sphericalCamera(10), itssaggregation(11)} (0..15)

SegmentCount               ::= INTEGER(1..127)

SpeedValueExtended         ::= INTEGER {standstill(0), oneCentimeterPerSec(1),unavailable(16383)}
(-16383..16383)

TimeOfMeasurement          ::= INTEGER {oneMilliSecond(1)} (-1500..1500)

VehicleSubclassType        ::= INTEGER {unknown(0), moped(1), motorcycle(2), passengerCar(3),
bus(4), lightTruck(5), heavyTruck(6), trailer(7), specialVehicles(8), tram(9),
emergencyVehicle(10), agricultural(11)} (0..255)

XSensorOffset                    ::= INTEGER {negativeZeroPointZeroOneMeter(-1), negativeOneMeter(-
100)} (-5000..0)

YSensorOffset                    ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100)} (-
1000..1000)

ZSensorOffset                    ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100)} (0..1000)

END
```

Annex B: Description of data elements and data frames

B.1 General Requirements

Mandatory data elements should be set to "unavailable" only under error conditions of temporary nature, when data are not available or erroneous due to any failure in the data provisioning facilities.

B.2 CPM header and management container

B.2.1 Introduction

The following clauses provide information about each Data Element and Data Frame which constitute a CPM. References to data type declarations are provided as applicable.

B.2.2 header

Description	ITS PDU header of the CPM. This DF includes DEs for the CPM *protocolVersion*, the CP message type identifier *messageID* and the station identifier *stationID* of the originating ITS-S. The DE *protocolVersion* is used to select the appropriate protocol decoder at the receiving ITS-S. This DE *messageID* should be harmonized with other V2X message identifier definitions.
Data setting and presentation requirements	For the present document, the value of the DE *protocolVersion* should be set to 1. For CPM, the DE *messageID* should be set to cpm (14). This DF should be presented as specified in ETSI TS 102 894-2 [i.4] *ItsPduHeader*.

B.2.3 cpm

Description	CPM Payload. It should include the time stamp of the CPM and the containers *managementContainer, stationDataContainer, sensorInformationContainer* and *perceivedObjectContainer.* The selection of the *StationDataContainer* type container depends on the *StationType* as selected in the *Management* container.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.2.4 generationDeltaTime

Description	See description in data type declaration.
Data setting and presentation requirements	This DE should be presented as specified in ETSI EN 302 637-2 [i.7].

B.2.5 cpmParameters

Description	The sequence of CPM mandatory and optional containers. Other containers may be added in the future.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.2.6 managementContainer

Description	The *managementContainer* comprises basic information about the originating ITS-S, which are not vehicle or RSU specific.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.2.7 stationType

Description	Station type of the originating ITS-S. For vehicle ITS-Ss the value of this DE should be set to one out of the values 3 to 10.
Data setting and presentation requirements	The DE should be presented as specified in ETSI TS 102 894-2 [i.4] *StationType*.

B.2.8 referencePosition

Description	The reference position indicates the location of the originating ITS station or an arbitrary position which should be used for referencing received objects.
Data setting and presentation requirements	The DF should be presented as specified in ETSI TS 102 894-2 [i.4] *ReferencePosition.*

B.2.9 perceivedObjectContainerSegmentInfo

Description	The perceived object container segment info describes the segmentation information in case the data for CPM transmission needs to be split up into multiple messages due to message size constraints.
Data setting and presentation requirements	The DF should be presented as defined in clause C.46.

B.2.10 numberOfPerceivedObjects

Description	The number of perceived objects by the transmitting ITS-S. This number does not have to match up with the number of objects included in the transmitted message due to the object inclusion scheme.
Data setting and presentation requirements	The DF should be presented as defined in clause C.48.

B.3 Station Data Container

B.3.1 stationDataContainer

Description	The main container type to provide more detailed description about the disseminating ITS-S. OriginatingVehicleContainer should be used in case the originating station is a vehicle, originatingRSUContainer should be used in case the originating station is a RSU.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.3.2 originatingVehicleContainer

Description	The *originatingVehicleContainer* provides detailed information about the vehicle ITS-S disseminating the CPM.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.3.3 heading

Description	Heading and heading accuracy of the vehicle movement of the originating ITS-S with regards to the true north. The heading accuracy provided in the DE *headingConfidenc*e value should provide the accuracy of the measured vehicle heading with a confidence level of 95 %.
Data setting and presentation requirements	The DE should be presented as specified in ETSI TS 102 894-2 [i.4] *Heading.*

B.3.4 speed

Description	Driving speed and speed accuracy of the originating ITS-S. The speed accuracy provided in the DE *speedConfidence* should provide the accuracy of the speed value with a confidence level of 95 %.
Data setting and presentation requirements	The DF should be presented as specified in ETSI TS 102 894-2 [i.4] *Speed.*

B.3.5 vehicleOrientationAngle

Description	Angle and angle accuracy of the absolute orientation of the disseminating vehicle in the WGS84 coordinate system with respect to true North. This is opposed to the vehicle heading which is calculated taking into account the speed vector. The confidence denotes the accuracy of the measured angle value for a confidence level of 95 %.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.3.6 driveDirection

Description	Denotes whether a vehicle is driving forward or backward. When the information is unavailable, the value should be set to 2.
Data setting and presentation requirements	The DE should be presented as specified in ETSI TS 102 894-2 [i.4] *DriveDirection.*

B.3.7 longitudinalAcceleration

Description	Vehicle longitudinal acceleration of the originating ITS-S at the reference point of the vehicle. It should include the measured vehicle longitudinal acceleration and its accuracy value with the confidence level of 95 %. Otherwise, the *longitudinalAccelerationConfidence* should be set to unavailable.
Data setting and presentation requirements	The data element should be presented as specified in ETSI TS 102 894-2 [i.4] *LongitudinalAcceleration.*

B.3.8 lateralAcceleration

Description	Vehicle lateral acceleration of the originating ITS-S at the reference point of the vehicle. It should include the measured vehicle lateral acceleration and its accuracy value with the confidence level of 95 %. This DE should be present if the data is available at the originating ITS-S.
Data setting and presentation requirements	The presentation and data setting rules should be as specified in ETSI TS 102 894-2 [i.4] *LateralAcceleration.*

B.3.9 verticalAcceleration

Description	Vehicle vertical acceleration of the originating ITS-S at the reference point of the vehicle. It should include the measured vehicle vertical acceleration and its accuracy value with the confidence level of 95 %. This DE should be present if the data is available at the originating ITS-S.
Data setting and presentation requirements	The presentation and data setting rules should be as specified in ETSI TS 102 894-2 [i.4] *VerticalAcceleration.*

B.3.10 yawRate

Description	The yawRate denotes the vehicle rotation around the centre of mass of the empty vehicle together with its confidence level.
Data setting and presentation requirements	The DF should be presented as specified in ETSI TS 102 894-2 [i.4] *YawRate.*

B.3.11 pitchAngle

Description	Angle and angle accuracy between the ground plane and the current orientation of the vehicle's x-axis with respect to the ground plane about the y-axis according to the ISO 8855 [i.2].
Data setting and presentation requirements	The DF should be presented as defined in annex A.

B.3.12 rollAngle

Description	Angle and angle accuracy between the ground plane and the current orientation of the vehicle's y-axis with respect to the ground plane about the x-axis according to the ISO 8855 [i.2]
Data setting and presentation requirements	The DF should be presented as defined in annex A.

B.3.13 vehicleLength

Description	Length of the Originating Vehicle.
Data setting and presentation requirements	The DF should be presented as specified in ETSI TS 102 894-2 [i.4].

B.3.14 vehicleWidth

Description	Width of the Originating Vehicle.
Data setting and presentation requirements	The DF should be presented as specified in CEN ISO/TS 19091 [i.5].

B.3.15 vehicleHeight

Description	Height of the Originating Vehicle.
Data setting and presentation requirements	The DF should be presented as specified in CEN ISO/TS 19091 [i.5].

B.3.16 trailerData

Description	Provides detailed information about the trailers dimensions and orientation in case a trailer is present.
Data setting and presentation requirements	The DF should be presented as defined in annex A.

B.3.17 refPointId

Description	Increasing counter of the trailer reference point (corresponding to the hitch point).
Data setting and presentation requirements	The DF should be presented as defined in clause C.2.

B.3.18 hitchPointOffset

Description	Position of the hitch point in negative x-direction (according to ISO 8855 [i.2]) from the vehicle Reference Point.
Data setting and presentation requirements	The DF should be presented as defined in clause C.3.

B.3.19 frontOverhang

Description	Length of the trailer overhang in the positive x direction (according to ISO 8855 [i.2]) from the trailer Reference Point indicated by the refPointID. The value defaults to 0 in case the trailer is not overhanging to the front with respect to the trailer reference point.
Data setting and presentation requirements	The DF should be presented as defined in clause C.4.

B.3.20 rearOverhang

Description	Length of the trailer overhang in the negative x direction (according to ISO 8855 [i.2]) from the trailer Reference Point indicated by the refPointID.
Data setting and presentation requirements	The DF should be presented as defined in clause C.5.

B.3.21 trailerWidth

Description	Width of the trailer. For a trailer width equal to or greater than 6,1 metres, the value should be set to 61. The value should be set to 62 if the information is unavailable.
Data setting and presentation requirements	The DF should be presented as defined in ETSI TS 102 894-2 [i.4] *VehicleWidth.*

B.3.22 hitchAngle

Description	Value and confidence of the angle between the trailer orientation (corresponding to the x direction of the ISO 8855 [i.2] coordinate system centered on the trailer) and the direction of the segment having as end points the reference point of the trailer and the reference point of the pulling vehicle, which can be another trailer or a vehicle looking on the horizontal plane xy, described in the local Cartesian coordinate system of the preceding reference point. The angle is measured with negative values considering the trailer orientation turning clockwise starting from the segment direction. The angle value accuracy is provided with the confidence level of 95 %.
Data setting and presentation requirements	The DF should be presented as specified in annex A.

B.3.23 originatingRSUContainer

Description	The *originatingRSUContainer* provides information about the RSU type ITS-S disseminating the CPM.
Data setting and presentation requirements	The DF should be presented as specified in annex A.

B.3.24 intersectionReferenceId

Description	Conveys the combination of an optional RoadRegulatorID and of an InterSectionID that is unique within that region. When the RoadRegulatorID is present the InterSectionReferenceID is guaranteed to be globally unique.
Data setting and presentation requirements	The DF should be presented as specified in annex A.

B.3.25 roadSegmentReferenceId

Description	Conveys the RoadSegmentReferenceID which is unique to a given road segment of interest, and also the RoadRegulatorID assigned to the region in which it is operating.
Data setting and presentation requirements	The DF should be presented as specified in annex A.

B.4 Sensor Information Container

B.4.1 sensorInformationContainer

Description	The optional sensor information container of the CPM. This DF includes of sensor identifier *id*, sensor type *type*, and a DF for providing sensor-*details*.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.4.2 sensorID

Description	Sensor pseudonym ID used to relate which measurement has been received by which sensor. This ID is referred to in the perceivedObjectContainer (Type sensorIDList).
Data setting and presentation requirements	This DE should be presented as defined in clause C.13.

B.4.3 type

Description	An enumerated value describing the type of the described sensor.
Data setting and presentation requirements	This DE should be presented as defined in clause C.31.

B.4.4 detectionArea

Description	Choice of DFs to detail the sensor information. It can be chosen from six different DFs to define the sensor details. The *vehicleSensor* should be used for describing non-stationary sensors attached to vehicles. The *stationarySensorRadial* provides details for describing sensors mounted to road-side units. The *stationarySensorPolygon* can be used to describe a polygonal detection area associated to a single sensor or to describe the union of multiple polygonal areas expressed as one combined polygon. In this case the sensor type is put to "fusion". The *stationarySensorCircular* describes a circular perception area for a stationary sensor. The position offset refers to the center point of the circular area. In this case the sensor type is put to "fusion". The *stationarySensorEllipse* describes an ellipse-shaped perception area for a stationary sensor. The position offset refers to the center point of the ellipse. In this case the sensor type is put to "fusion". The *stationarySensorRectangle* describes a rectangle as a perception area for a stationary sensor. The position offset refers to the center point of the rectangle. In this case the sensor type is put to "fusion".
Data setting and presentation requirements	This DF should be represented as defined in annex A.

B.4.5 vehicleSensor

Description	A container used to describe the perception capabilities of for mobile sensors mounted to vehicles.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.4.6 refPointId (SensorInformationContainer)

Description	An identification of the reference point in case of a sensor mounted to trailer. Defaults to ITS ReferencePoint (0).
Data setting and presentation requirements	This DE should be presented as defined in clause C.2.

B.4.7 xSensorOffset

Description	Mounting position of sensor in negative x-direction from Reference Point indicated by the refPointID (clause B.4.6).
Data setting and presentation requirements	This DE should be presented as defined in clause C.32.

B.4.8 ySensorOffset

Description	Mounting position of sensor in y-direction from Reference Point indicated by the refPointID (clause B.4.6).
Data setting and presentation requirements	This DE should be presented as defined in clause C.33.

B.4.9 zSensorOffset

Description	Mounting position of sensor in z-direction from Reference Point indicated by the refPointID (clause B.4.6).
Data setting and presentation requirements	This DE should be presented as defined in clause C.34.

B.4.10 vehicleSensorProperties

Description	The actual extension of the area covered by the specific vehicle sensor. In case of multiple perception areas for a sensor, a list of areas covered by this sensor can be added.
Data setting and presentation requirements	This DE should be presented as defined in clause C.35.

B.4.11 range

Description	Range of sensor within the indicated OpeningAngle.
Data setting and presentation requirements	This DE should be presented as defined in clause C.42.

B.4.12 horizontalOpeningAngleStart

Description	Start of the sensor's horizontal OpeningAngle extension relative to the body of the vehicle. The value is provided with respect to a body-fixed coordinate system according to the ISO 8855 [i.2] specification with angles counted positive in the counter-clockwise direction starting from the X-axis. The opening angle always extends from the horizontalOpeningAngleStart to horizontalOpeningAngleEnd in counter-clockwise direction.
Data setting and presentation requirements	This DE should be presented as defined in clause C.22.

B.4.13 horizontalOpeningAngleEnd

Description	End of the sensor's horizontal OpeningAngle extension relative to the body of the vehicle. The value is provided with respect to a body-fixed coordinate system according to the ISO 8855 [i.2] specification with angles counted positive in the counter-clockwise direction starting from the X-axis. The opening angle always extends from the horizontalOpeningAngleStart to the horizontalOpeningAngleEnd in counter-clockwise direction.
Data setting and presentation requirements	This DE should be presented as defined clause C.22.

B.4.14 stationaryHorizontalOpeningAngleStart

Description	Start of the stationary sensor's horizontal Opening Angle extension relative to WGS84 north. The opening angle always extends from the stationaryHorizontalOpeningAngleStart to the stationaryHorizontalOpeningAngleEnd in clockwise direction.
Data setting and presentation requirements	This DE should be presented as defined in clause C.21.

B.4.15 stationaryHorizontalOpeningAngleEnd

Description	End of the stationary sensor's horizontal Opening Angle extension relative to WGS84 north. The opening angle always extends from the stationaryHorizontalOpeningAngleStart to the stationaryHorizontalOpeningAngleEnd in clockwise direction.
Data setting and presentation requirements	This DE should be presented as defined in clause C.21.

B.4.16 verticalOpeningAngleStart

Description	Start of the sensor's vertical OpeningAngle extension. This is an optional DE. The angle refers to a rotation about the y-axis of a sensor-specific coordinate system with its origin located at the location defined by the offset. The x-axis of the sensor's coordinate system points in the direction of half of the horizontalOpeningAngle.
Data setting and presentation requirements	This DE should be presented as defined in clause C.22.

B.4.17 verticalOpeningAngleEnd

Description	End of the sensor's vertical OpeningAngle extension. This is an optional DE. The angle refers to a rotation about the y-axis of a sensor-specific coordinate system with its origin located at the location defined by the offset. The X-axis of the sensor's coordinate system points in the direction of half of the horizontalOpeningAngle.
Data setting and presentation requirements	This DE should be presented as defined in clause C.22.

B.4.18 stationarySensorRadial

Description	The container describing the sensor measurement characteristics of a stationary sensor mounted to road-side units.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.4.19 sensorPositionOffset

Description	DF providing xOffSet, yOffset, and height of sensor position relative to the provided reference position.
Data setting and presentation requirements	• xOffset and yOffset values are represented as specified in SAE J2735 [i.6] *NodeOffsetPointXY*. • Sensor height is described in clause C.43.

B.4.20 sensorHeight

Description	Height of sensor position relative to altitude provided by the reference position.
Data setting and presentation requirements	This DE should be presented as defined in clause C.43.

B.4.21 stationarySensorPolygon

Description	The container describing the sensor measurement characteristics by a polygon area.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.4.22 polyPoint

Description	x and y offset of position relative to the provided reference position in an horizontal plane containing a coordinate system where y corresponds to the North direction and x with the East direction.
Data setting and presentation requirements	This DE should be presented as specified in SAE J2735 [i.6] *NodeOffsetPointXY*.

B.4.23 stationarySensorCircular

Description	The container describing the sensor measurement characteristics by a circular area. This DF should include a radius and an optional offset from the applicable reference point.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.4.24 nodeCenterPoint

Description	x and y offset of position relative to the provided reference position in a horizontal plane containing a coordinate system where y corresponds to the North direction and x with the East direction. Optional in case reference point is also center of the description.
Data setting and presentation requirements	The DE node should be presented as specified in SAE J2735 [i.6] *NodeOffsetPointXY*.

B.4.25 radius

Description	The radius of the sensor area in the shape of a circle.
Data setting and presentation requirements	This DE should be presented as defined in clause C.44.

B.4.26 stationarySensorEllipse

Description	Container describing the sensor measurement characteristics by a circular area. This DF should include: • an optional DE nodeCenterPoint; • DE semiMinorRangeLength; • DE semiMajorRangeLength; • DE semiMajorRangeOrientation.
Data setting and presentation requirements	The DE nodeCenterPoint should be presented as defined in SAE J2735 [i.6] NodeOffsetPointXY. The DE SemiMinorRangeLength and SemiMajorRangeLength should be presented as defined in clause C.45. The DE semiMajorRangeOrientation should be presented as defined in clause C.21.

B.4.27 semiMinorRangeLength

Description	Length of the minor/secondary radius of an ellipse or rectangle.
Data setting and presentation requirements	This DE should be presented as defined in clause C.45.

B.4.28 semiMajorRangeLength

Description	Length of the major/primary radius of an ellipse or rectangle.
Data setting and presentation requirements	This DE should be presented as defined in clause C.45.

B.4.29 semiMajorRangeOrientation

Description	Orientation of the ellipse/rectangle major range of the sensor area ellipse/rectangle with regards to WGS84 north.
Data setting and presentation requirements	This DE should be presented as defined in clause C.21.

B.4.30 stationarySensorRectangle

Description	Container describing the sensor measurement characteristics by a rectangular area. This DF should include: • an optional DE nodeCenterPoint; • DE semiMajorRangeLength; • DE semiMinorRangeLength; • DE semiMajorRangeOrientation.
Data setting and presentation requirements	The DE nodeCenterPoint should be presented as specified in SAE J2735 [i.6] NodeOffsetPointXY. The DE SemiMinorRangeLength and SemiMajorRangeLength should be presented as defined in clause C.45. The DE semiMajorRangeOrientation should be presented as defined in clause C.21.

B.4.31 freeSpaceConfidence

Description	Describes the isotropic free space confidence that can be assumed for the entire detection area of this sensor. Shadowed areas can be derived from provided objects. Deviations from this free space derivation can be expressed in the *FreeSpaceAddendum*.
Data setting and presentation requirements	This DE should be presented as defined in clause C.50.

B.5 Perceived Object Container

B.5.1 perceivedObjectContainer

Description	The optional perceived object container of the CPM. Other types of perceived object containers may be added in the future.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.5.2 objectID

Description	Identifier assigned to a detected object which remains constant as long as the object is perceived by the disseminating ITS-S. Numbers are assigned in an increasing round-robin fashion. When the last identifier in the allowed range has been used, the first counter for the identifier starts from the beginning of the range again.
Data setting and presentation requirements	This DF should be presented as defined in clause C.13.

B.5.3 sensorIDList

Description	List of sensor-IDs which provided the measurement data. Refers to the sensorID in the SensorInformationContainer.
Data setting and presentation requirements	This DF should be presented as defined in clause C.61.

B.5.4 timeOfMeasurement

Description	Provides the time difference from the message's generation delta time to the time of the measurement of the object.
Data setting and presentation requirements	This DE should be presented as defined in clause C.6.

B.5.5 objectAge

Description	Provides the age of the detected and described object.
Data setting and presentation requirements	This DE should be presented as defined in clause C.7.

B.5.6 objectConfidence

Description	The confidence associated to the object.
Data setting and presentation requirements	This DE should be presented as defined in clause C.8.

B.5.7 xDistance

Description	Absolute distance to detected object from the ITS-S's reference point in x-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as defined in clause C.14.

B.5.8 yDistance

Description	Absolute distance to detected object from the ITS-S's reference point in y-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as defined in clause C.14.

B.5.9 zDistance

Description	Absolute distance to detected object from the ITS-S's reference point in z-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as defined in clause C.14.

B.5.10 xSpeed

Description	Relative speed of detected object from the ITS-S's reference point in x-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as defined in clause C.17.

B.5.11 ySpeed

Description	Relative speed of detected object from the ITS-S's reference point in y-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as defined in clause C.17.

B.5.12 zSpeed

Description	Relative speed of detected object from the ITS-S's reference point in z-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as defined in clause C.17.

B.5.13 xAcceleration

Description	Relative acceleration of detected object from the ITS-S's reference point in x-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as specified in ETSI TS 102 894-2 [i.4] *LongitudinalAcceleration*.

B.5.14 yAcceleration

Description	Relative acceleration of detected object from the ITS-S's reference point in y-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as specified in ETSI TS 102 894-2 [i.4] *LateralAcceleration*.

B.5.15 zAcceleration

Description	Relative acceleration of detected object from the ITS-S's reference point in z-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45.
Data setting and presentation requirements	This DF should be presented as specified in ETSI TS 102 894-2 [i.4] *VerticalAcceleration*.

B.5.16 yawAngle

Description	Relative yaw angle of object from the ITS-S's reference point. For a vehicle, it is according to the vehicle x direction in the coordinate system provided by ISO 8855 [i.2]. For a RSU, it is according to the x direction in a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction, as outlined in Figure 45. The angle is measured with positive values considering the object orientation turning counter-clockwise starting from the x-direction. 3601 should be set if the value is unavailable The yaw angle confidence is described with a predefined confidence level of 95 % for the component.
Data setting and presentation requirements	This DF should be presented as defined in annex A.

B.5.17 planarObjectDimension1

Description	First dimension of object as provided by the sensor or environment model. This dimension is always contained in the plane which is perpendicular to the direction of the angle indicated by the yawAngle and which contains the object reference point.
Data setting and presentation requirements	This DF should be presented as defined in clause C.24.

B.5.18 planarObjectDimension2

Description	Second dimension of the object as provided by the sensor environment model. This dimension is contained in the plane which contains the direction of the angle indicated by the yawAngle and the object reference point.
Data setting and presentation requirements	This DF should be presented as defined in clause C.24.

B.5.19 verticalObjectDimension

Description	Vertical dimension of object as provided by the sensor or object model.
Data setting and presentation requirements	This DF should be presented as defined in clause C.24.

B.5.20 objectRefPoint

Description	The reference point on the perceived object relative to which the measurement data is provided. In case no object reference - point can be determined, it is assumed to be the center point of the detected object.
Data setting and presentation requirements	This DF should be presented as defined in clause C.9.

B.5.21 dynamicStatus

Description	The classification of a perceived object towards its capabilities to move.
Data setting and presentation requirements	This DF should be presented as defined in clause C.10.

B.5.22 classification

Description	Provides the classification of the described object. Multi-dimensional classification may be provided along with confidences.
Data setting and presentation requirements	This DF should be presented as defined in clause C.51.

B.5.23 matchedPosition

Description	The optional map-matched position of an object.
Data setting and presentation requirements	This DF should be presented as defined in clause C.27.

B.6 Free Space Addendum Container

B.6.1 freeSpaceConfidence

Description	Describes an isotropic free space confidence that applies to the entire area as defined in the freeSpaceArea of a particular free space addendum container.
Data setting and presentation requirements	This DF should be presented as defined in clause C.50.

B.6.2 freeSpaceArea

Description	Describes the free space area for which the free space confidence of this addendum container is valid.
Data setting and presentation requirements	This DF should be presented as defined in clause C.49.

B.6.3 sensorIdList

Description	Provides a list of pseudonym sensor IDs which performed the measurement to indicate the free space.
Data setting and presentation requirements	This DF should be presented as defined in clause C.61.

B.6.4 shadowingApplies

Description	Indicates if the shadowing applies also within the described area.
Data setting and presentation requirements	This DF should be presented as defined in clause C.63.

Annex C:
Definition of Data Types

C.1 Introduction

The CDD-like definitions in the clauses below represent novel data types that are unique to the CP Message and may be considered for adoption as part of the Common Data Dictionary ETSI TS 102 894-2 [i.4].

C.2 DE_RefPointId

Descriptive Name	refPointId
ASN.1 representation	`RefPointId ::= INTEGER (0..255)`
Definition	Reference point counter for a trailer
Unit	N/A

C.3 DE_HitchPointOffset

Descriptive Name	hitchPointOffset
ASN.1 representation	`HitchPointOffset ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..100)`
Definition	Position of the hitch point in negative x-direction (according to ISO 8855 [i.2]) from the vehicle Reference Point
Unit	0,1 m

C.4 DE_FrontOverhang

Descriptive Name	frontOverhang
ASN.1 representation	`FrontOverhang ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(10)} (0..50)`
Definition	Length of the trailer overhang in the positive x direction (according to ISO 8855 [i.2]) from the trailer Reference Point indicated by the refPointID. The value defaults to 0 in case the trailer is not overhanging to the front with respect to the trailer reference point
Unit	0,1 m

C.5 DE_RearOverhang

Descriptive Name	rearOverhang
ASN.1 representation	`RearOverhang ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..150)`
Definition	Length of the trailer overhang in the negative x direction (according to ISO 8855 [i.2]) from the trailer Reference Point indicated by the refPointID
Unit	0,1 m

C.6 DE_TimeOfMeasurement

Descriptive Name	timeOfMeasurement
ASN.1 representation	`TimeOfMeasurement ::= INTEGER {oneMilliSecond(1)} (-1500..1500)`
Definition	Time difference with respect to the generationDeltaTime for the provided measurement. Negative values indicate that the provided object state refers to a point in time after the generationDeltaTime has been computed, i.e. after the latest disseminating ITS-S position update which is used to calculate the generationDeltaTime
Unit	ms

C.7 DE_ObjectAge

Descriptive Name	objectAge
ASN.1 representation	`ObjectAge ::= INTEGER { oneMiliSec(1) } (0..1500)`
Definition	Age of object in milliseconds, i.e. for how long the object has been observed on the disseminating station. A value of 1 500 indicates that the object has been observed for more than 1,5 s
Unit	ms

C.8 DE_ObjectConfidence

Descriptive Name	objectConfidence
ASN.1 representation	`ObjectConfidence ::= INTEGER {unknown(0), onePercent(1), oneHundredPercent(100), unavailable(101)} (0..101)`
Definition	The confidence in the existence of the object and its characteristics as indicated by the perceivedObject container. The value should be set to: • Unknown (0): if the object confidence is unknown • A value between 1 and 100 to express the confidence • Unavailable (101): if the confidence could not be computed and does not apply The required confidence level is defined by the corresponding standards applying the DE
Unit	N/A

C.9 DE_ObjectRefPoint

Descriptive Name	objectRefPoint
ASN.1 representation	`ObjectRefPoint ::= INTEGER {mid (0), bottomLeft(1), midLeft(2), topLeft(3), bottomMid(4), topMid(5), bottomRight(6), midRight(7), topRight(8)} (0..8)`
Definition	Reference point of measurement for the object dimensions. All provided state variables of this object are given relative to the reference point. The point is included in the plane perpendicular to the direction of the yawAngleValue
Unit	N/A

C.10 DE_DynamicStatus

Descriptive Name	dynamicStatus
ASN.1 representation	`DynamicStatus ::= INTEGER {dynamic(0), hasBeenDynamic(1), static(2)} (0..2)`
Definition	Indication whether the detected object is classified as a dynamic (i.e. moving) object. This value indicates whether an object has the general capability to move (0), i.e. change its position. "Has been dynamic" (1) indicates whether an object has been dynamic before, e.g. a car stopping at a traffic light. Static (2) should be used in case an object is identified to be not moving throughout any previous observation
Unit	N/A

C.11 DF_MatchedPosition

Descriptive Name	matchedPosition

ASN.1 representation	`MatchedPosition ::= SEQUENCE {`
	`    laneID                      LaneID OPTIONAL,`
	`    longitudinalLanePosition    LongitudinalLanePosition OPTIONAL,`
	`    ...`
	`}`

Definition	Indicates the position of the object mapped on the intersection topology description transmitted in MAP messages. The DF should include the following information: • laneID: conveys an assigned index that is unique within the intersection with InterSectionReferenceId of the OriginatingRSUContainer. It should be presented as specified in clause 7.88 of SAE J2735 [i.6] • longitudinalLanePosition: Indicates longitudinal offset of the map-matched position of the object along the lane
Unit	N/A

C.12 DF_LongitudinalLanePosition

Descriptive Name	longitudinalLanePosition

ASN.1 representation	`LongitudinalLanePosition ::= SEQUENCE {`
	`    longitudinalLanePositionValue`
	`LongitudinalLanePositionValue,`
	`    longitudinalLanePositionConfidence`
	`LongitudinalLanePositionConfidence`
	`}`

Definition	Estimated position along the longitudinal length of a particular lane The DF should include the following data: • longitudinalLanePositionValue: The mean value of the longitudinal position within a particular length. It should be presented as defined in clause C.29 • longitudinalLanePositionConfidence: The confidence associated to the provided value. It should be presented as defined in clause C.30

C.13 DE_Identifier

Descriptive Name	Identifier
ASN.1 representation	`Identifier ::= INTEGER (0..255)`
Definition	General identifier data element
Unit	N/A

C.14 DF_ObjectDistanceWithConfidence

Descriptive Name	Object distance with confidence indication

ASN.1 representation	`ObjectDistanceWithConfidence ::= SEQUENCE {`
	`    value        DistanceValue,`
	`    confidence   DistanceConfidence`
	`}`

Definition	A general Data Frame (DF) to describe a distance component along with a confidence with a predefined confidence level of 95 % for the component The DF should include the following information: • value: The distance value which can be estimated as the mean of the current distribution. It should be presented as defined in clause C.15 • confidence: The confidence value associated to the provided value. It should be presented as defined in clause C.16
Unit	N/A

C.15 DE_DistanceValue

Descriptive Name	distanceValue
ASN.1 representation	`DistanceValue            ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100)} (-132768..132767)`
Definition	Distance from one point to another
Unit	0,01 m

C.16 DE_DistanceConfidence

Descriptive Name	distanceConfidence
ASN.1 representation	`DistanceConfidence       ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100), outOfRange(101), unavailable(102)} (0..102)`
Definition	Absolute accuracy of measurement to a confidence level of 95 %, 101 should be set if the accuracy is out of range, 102 should be set if the accuracy data is unavailable
Unit	0,01 m

C.17 DF_SpeedExtended

Descriptive Name	speedExtended

ASN.1 representation	`SpeedExtended ::= SEQUENCE {`
	`    value       SpeedValueExtended,`
	`    confidence  SpeedConfidence`
	`}`

Definition	A general Data Frame (DF) to describe a speed component along with a confidence with a predefined confidence level of 95 % for the component The DF should include the following information: • value: The speed value which can be estimated as the mean of the current distribution. It should be presented as defined in clause C.20 • confidence: The speed value confidence associated to the provided value. It should be presented as defined in ETSI TS 102 894-2 [i.4] SpeedConfidence
Unit	N/A

C.18 DF_WGS84Angle

Descriptive Name	Wgs84Angle

ASN.1 representation	`WGS84Angle ::= SEQUENCE {`
	`    value       WGS84AngleValue,`
	`    confidence  AngleConfidence`
	`}`

Definition	A general Data Frame (DF) to describe an angular component along with a confidence with a predefined confidence level of 95 % for the component in the WGS84 coordinate system The DF should include the following information: • value: The speed value which can be estimated as the mean of the current distribution. It should be presented as defined in clause C.21 • confidence: The speed value confidence associated to the provided value. It should be presented as defined in clause C.23
Unit	N/A

C.19 DF_CartesianAngle

Descriptive Name	Wgs84Angle

ASN.1 representation	`CartesianAngle ::= SEQUENCE {`
	`    value       CartesianAngleValue,`
	`    confidence  AngleConfidence`
	`}`

Definition	A general Data Frame (DF) to describe an angular component along with a confidence with a predefined confidence level of 95 % for the component in a Cartesian coordinate system The DF should include the following information: • value: The speed value which can be estimated as the mean of the current distribution. It should be presented as defined in clause C.22 • confidence: The speed value confidence associated to the provided value. It should be presented as defined in clause C.23

C.20 DE_SpeedValueExtended

Descriptive Name	speedValueExtended
ASN.1 representation	`SpeedValueExtended        ::= INTEGER {standstill(0),` `oneCentimeterPerSec(1),unavailable(16383)} (-16383..16383)`
Definition	Speed value for perceived object described in ITS Reference Frame. For values equal to or greater than 163,82 m/s, the value should be set to 16 382. When the information is not available, the value should be set to 16 383
Unit	0,01 m/s

C.21 DE_WGS84AngleValue

Descriptive Name	WGS84AngleValue

ASN.1 representation	`WGS84AngleValue           ::= INTEGER {wgs84North(0),`
	`wgs84East(900), wgs84South(1800), wgs84West(2700),`
	`unavailable(3601)} (0..3601)`

Definition	An angle value in degrees described in the WGS84 reference system with respect to the WGS84 north When the information is not available, the DE should be set to 3601
Unit	0,1 degrees

C.22 DE_CartesianAngleValue

Descriptive Name	cartesianAngleValue
ASN.1 representation	`CartesianAngleValue ::= INTEGER {zeroPointOneDegree(1), oneDegree(10), unavailable(3601)} (0..3601)`
Definition	An angle value in degrees described in a local Cartesian coordinate system, counted positive in a right-hand local coordinate system from the abscissa When the information is not available, the DE should be set to 3601
Unit	0,1 degrees

C.23 DE_AngleConfidence

Descriptive Name	angleConfidence
ASN.1 representation	`AngleConfidence ::= INTEGER {zeroPointOneDegree (1), oneDegree (10), outOfRange(126), unavailable(127)} (1..127)`
Definition	The absolute accuracy of a reported angle value for a predefined confidence level (e.g. 95 %). The required confidence level is defined by the corresponding standards applying the DE The value should be set to: • 1 if the heading accuracy is equal to or less than 0,1 degree • n (n > 1 and n < 125) if the heading accuracy is equal to or less than n × 0,1 degree • 125 if the heading accuracy is equal to or less than 12,5 degrees • 126 if the heading accuracy is out of range, i.e. greater than 12,5 degrees • 127 if the heading accuracy information is not available If an angle value is received and its confidence is set to 'outOfRange(126)', it means that the reported angle value is not valid and therefore cannot be trusted. Such value is not useful for the application
Unit	0,1 degrees

C.24 DF_ObjectDimension

Descriptive Name	objectDimension

ASN.1 representation	`ObjectDimension ::= SEQUENCE {`
	`    value       ObjectDimensionValue,`
	`    confidence  ObjectDimensionConfidence`
	`}`

Definition	A general Data Frame (DF) to describe a dimension of an object along with a confidence with a predefined confidence level of 95 % for the component The DF should include the following information: • value: The object dimension value which can be estimated as the mean of the current distribution. It should be presented as defined in clause C.25 • confidence: The dimension accuracy associated to the provided value. It should be presented as defined in clause C.26
Unit	N/A

C.25 DE_ObjectDimensionValue

Descriptive Name	objectDimensionValue
ASN.1 representation	`ObjectDimensionValue ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..1023)`
Definition	An object Dimension in meter.
Unit	0,1 m

C.26 DE_ObjectDimensionConfidence

Descriptive Name	objectDimensionConfidence
ASN.1 representation	`ObjectDimensionConfidence ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100), outOfRange(101), unavailable(102)} (0..102)`
Definition	Accuracy of provided dimension value with a predefined confidence level (e.g. 95 %) 0 should indicate that the accuracy is not available
Unit	0,01 m

C.27 DF_MatchedPosition

Descriptive Name	matchedPosition

ASN.1 representation	`MatchedPosition ::= SEQUENCE {`
	`    laneID                      LaneID OPTIONAL,`
	`    longitudinalLanePosition    LongitudinalLanePosition OPTIONAL,`
	`    ...`
	`}`

Definition	Indicates the position of the object mapped on the intersection topology description transmitted in MAP messages
Unit	N/A

C.28 DE_OffsetPoint

Descriptive Name	offsetPoint

ASN.1 representation	`OffsetPoint ::= SEQUENCE{`
	`    nodeOffsetPointxy   NodeOffsetPointXY (WITH COMPONENTS {..., node-LatLon ABSENT, regional ABSENT}),`
	`    nodeOffsetPointZ    NodeOffsetPointZ OPTIONAL`
	`}`

Definition	Describes an offset position in a two- or three-dimensional plane as imported from CEN ISO/TS 19091 [i.5]. The first offset point is relative to the reference position of the ITS-S, subsequent entries become offset from that point. Excludes the `node-LatLon` DF and `regional` DF defined therein. The vertical offset in Z-direction should be represented as defined in clause C.62
Unit	N/A

C.29 DE_LongitudinalLanePositionValue

Descriptive Name	longitudinalLanePositionValue
ASN.1 representation	`LongitudinalLanePositionValue  ::= INTEGER {zeroPointOneMeter(1)} (0..32767)`
Definition	Indicates longitudinal offset of the map-matched position of a particular object along the matched lane, beginning from the lane's starting point as defined in CEN ISO/TS 19091 [i.5]
Unit	0,1 m

C.30 DE_LongitudinalLanePositionConfidence

Descriptive Name	longitudinalLanePositionConfidence
ASN.1 representation	`LongitudinalLanePositionConfidence ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100), outOfRange(101), unavailable(102)} (0..102)`
Definition	Absolute accuracy of longitudinal lane position measurement to a confidence level of 95 %, 101 should be set if the accuracy is out of range, 102 should be set if the accuracy data is unavailable
Unit	0,01 m

C.31 DE_SensorType

Descriptive Name	sensorType
ASN.1 representation	`SensorType ::= INTEGER {undefined(0), radar(1), lidar(2), monovideo(3), stereovision(4), nightvision(5), ultrasonic(6), pmd(7), fusion(8), inductionloop(9), sphericalCamera(10), itssaggregation(11)} (0..15)`
Definition	Describes the type of attached sensor. The following types are defined: undefined(0), radar(1), lidar(2), monovideo(3), stereovision(4), nightvision (5), ultrasonic (6) pmd (7), fusion (8), inductionlopp(9), spherical camera(10) and ITS-S aggregation (11)
Unit	N/A

C.32 DE_XSensorOffset

Descriptive Name	xSensorOffset
ASN.1 representation	`XsensorOffset ::= INTEGER {negativeZeroPointZeroOneMeter(-1), negativeOneMeter(-100)} (-5000..0)`
Definition	Describes the mounting position of a sensor along the negative x-direction from Reference Point indicated by the refPointID (see clause C.2)
Unit	0,01 m

C.33 DE_YSensorOffset

Descriptive Name	ySensorOffset
ASN.1 representation	`YOffset ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100)} (-1000..1000)`
Definition	Described the mounting position of a sensor in y-direction from Reference Point indicated by the refPointID (see clause C.2)
Unit	0,01 m

C.34 DE_ZSensorOffset

Descriptive Name	zSensorOffset
ASN.1 representation	`ZOffset ::= INTEGER {zeroPointZeroOneMeter(1), oneMeter(100)} (0..1000)`
Definition	Mounting position of sensor in z-direction from Reference Point indicated by the refPointID (see clause C.2)
Unit	0,01 m

C.35 DF_VehicleSensorProperties

Descriptive Name	vehicleSensorProperties

ASN.1 representation	`VehicleSensorProperties ::= SEQUENCE {`
	`    range                          Range,`
	`    horizontalOpeningAngleStart    CartesianAngleValue,`
	`    horizontalOpeningAngleEnd      CartesianAngleValue,`
	`    verticalOpeningAngleStart      CartesianAngleValue OPTIONAL,`
	`    verticalOpeningAngleEnd        CartesianAngleValue OPTIONAL,`
	`    ...`
	`}`

Definition	Describes the sensor characteristics when mounted to a vehicle. This DF should provide the following information: • Range: Length (range) of the sensor perception area as defined in clause C.42 • horizontalOpeningAngleStart: beginning of horizontal opening angle as defined in clause C.22 • horizontalOpeningAngleEnd: end of horizontal opening angle as defined in clause C.22 • verticalOpeningAngleStart: optional beginning of vertical opening angle as defined in clause C.22 • verticalOpeningAngleEnd: optional end of vertical opening angle as defined in clause C.22
Unit	N/A

C.36 DF_AreaRectangle

Descriptive Name	areaRectangle

ASN.1 representation	`AreaRectangle ::= SEQUENCE {`
	`    nodeCenterPoint            OffsetPoint OPTIONAL,`
	`    semiMajorRangeLength       SemiRangeLength,`
	`    semiMinorRangeLength       SemiRangeLength,`
	`    semiMajorRangeOrientation  WGS84AngleValue`
	`}`

Definition	Describes a rectangular area. The rectangle is centred about the reference point of the ITS-S or about the nodeCenterPoint (if provided) The DF should include the following information: • nodeCenterPoint: optional offset point about which the rectangle is centred with respect to the reference position of the ITS-S. It should be represented as defined in clause C.28 • semiMajorRangeLength: half length of the rectangle. It should be represented as defined in clause C.45 • semiMinorRangeLength: half width of the rectangle. It should be represented as defined in clause C.45 • semiMajorRangeOrientation: orientation of the semiMajorRangeLength of the rectangle in the WGS84 coordinate system. It should be represented as defined in clause C.21
Unit	N/A

C.37 DF_AreaEllipse

Descriptive Name	areaEllipse

ASN.1 representation	`AreaEllipse ::= SEQUENCE {`
	`    nodeCenterPoint             OffsetPoint OPTIONAL,`
	`    semiMinorRangeLength        SemiRangeLength,`
	`    semiMajorRangeLength        SemiRangeLength,`
	`    semiMajorRangeOrientation   WGS84AngleValue`
	`}`

Definition	Describes an elliptical area. The ellipse is centred about the reference point of the ITS-S or about the nodeCenterPoint (if provided) The DF should include the following information: • nodeCenterPoint: optional offset point about which the ellipse is centred with respect to the reference position of the ITS-S. It should be represented as defined in clause C.28 • semiMajorRangeLength: major radius of the ellipse. It should be represented as defined in clause C.45 • semiMinorRangeLength: minor radius of the rectangle. It should be represented as defined in clause C.45 • semiMajorRangeOrientation: orientation of the semiMajorRangeLength of the ellipse in the WGS84 coordinate system. It should be represented as defined in clause C.21
Unit	N/A

C.38 DF_AreaCircular

Descriptive Name	areaCircular

ASN.1 representation	`AreaCircular ::= SEQUENCE {`
	`    nodeCenterPoint      OffsetPoint OPTIONAL,`
	`    radius               Radius`
	`}`

Definition	Describes a circular area. The circle is centred about the reference point of the ITS-S or about the nodeCenterPoint (if provided) The DF should include the following information: • nodeCenterPoint: optional offset point about which the circle is centred with respect to the reference position of the ITS-S. It should be represented as defined in clause C.28 • radius: radius of the circular area. It should be represented as defined in clause C.45
Unit	N/A

C.39 DF_AreaPolygon

Descriptive Name	areaPolygon

ASN.1 representation	`AreaPolygon ::= SEQUENCE {`
	`    polyPointList   PolyPointList`
	`}`

Definition	Describes a polygonal area constructed by connecting the provided offset points in the sequence provided. The last point should be connected with the first point to close the described area The DF should include the following information: • polypoint: a sequence of offset points from the reference position of the ITS-S. It should be represented as defined in clause C.40
Unit	N/A

C.40 DF_PolyPointList

Descriptive Name	polyPoinList
ASN.1 representation	`PolyPointList ::= SEQUENCE (SIZE(3..16, ...)) OF OffsetPoint`
Definition	Describes a list of points representing a polygon. The last point should be connected with the first point to close the polygon It should be represented as defined in clause C.28
Unit	N/A

C.41 DF_AreaRadial

Descriptive Name	areaRadial

ASN.1 representation	`AreaRadial ::= SEQUENCE {`
	`    range Range,`
	`    stationaryHorizontalOpeningAngleStart   WGS84AngleValue,`
	`    stationaryHorizontalOpeningAngleEnd     WGS84AngleValue,`
	`    verticalOpeningAngleStart               CartesianAngleValue`
	`OPTIONAL,`
	`    verticalOpeningAngleEnd                 CartesianAngleValue`
	`OPTIONAL,`
	`    sensorPositionOffset OffsetPoint OPTIONAL,`
	`    sensorHeight SensorHeight OPTIONAL,`
	`    ...`
	`}`

Definition	Describes a radial area scanned by a stationary sensor. The triangular or cone-shaped area is constructed by sweeping the provided range about the reference point of the ITS-S or about the point described by the sensor offset point (if provided) with respect to the reference point between a horizontal start and a horizontal end angle in positive angular direction of the WGS84 coordinate system. A vertical opening angle may be provided in a Cartesian coordinate system with the x-axis located in the North-East plane of the WGS84 coordinate system. The sensor height may be provided to reflect characteristics of sensors mounted at an altitude (e.g. sensors mounted above intersections) The DF should include the following information: • range: The radial range of the sensor. It should be represented as defined in clause C.42 • stationaryHorizontalOpeningAngleStart: The orientation indicating the beginning of the stationary sensor's horizontal opening angle in positive angular direction with respect to the WGS84 coordinate system. It should be represented as defined in clause C.18 • stationaryHorizontalOpeningAngleEnd: The orientation indicating the end of the stationary sensor's horizontal opening angle in positive angular direction with respect to the WGS84 coordinate system. It should be represented as defined in clause C.18 • verticalOpeningAngleStart: The orientation indicating the beginning of the stationary sensor's vertical opening angle in positive angular direction of a Cartesian coordinate system with its x-axis located in the North-east plane of the WGS84 coordinate system. It should be represented as defined in clause C.19 • verticalOpeningAngleEnd: The orientation indicating the end of the stationary sensor's vertical opening angle in positive angular direction of a Cartesian coordinate system with its x-axis located in the North-east plane of the WGS84 coordinate system. It should be represented as defined in clause C.19 • sensorHeight: The height of the sensor mounting point. It should be represented as defined in clause C.43
Unit	-

C.42 DE_Range

Descriptive Name	range
ASN.1 representation	`Range ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..10000)`
Definition	Range of sensor within the indicated azimuth Angle defined by the start and end opening angle
Unit	0,1 m

C.43 DE_SensorHeight

Descriptive Name	sensorHeight
ASN.1 representation	`SensorHeight ::= INTEGER  {zeroPointZeroOneMeter(1)} (-5000..5000)`
Definition	Height of sensor position relative to altitude provided by the reference position
Unit	0,01 m

C.44 DE_Radius

Descriptive Name	radius
ASN.1 representation	`Radius ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)}  (0..10000)`
Definition	The dimension of a sensor area in the shape of a circle or a rectangle
Unit	0,1 m

C.45 DE_SemiRangeLength

Descriptive Name	SemiRangeLength
ASN.1 representation	`SemiRangeLength          ::= INTEGER {zeroPointOneMeter(1), oneMeter(10)} (0..10000)`
Definition	The length of an axis of an ellipsoid or rectangle, used to describe the extension in a particular direction
Unit	0,1 m

C.46 DF_PerceivedObjectContainerSegmentInfo

Descriptive Name	PerceivedObjectContainerSegmentInfo

ASN.1 representation	`PerceivedObjectContainerSegmentInfo ::= SEQUENCE {`
	`    totalMsgSegments    SegmentCount,`
	`    thisSegmentNum      SegmentCount`
	`}`

Definition	Information about segmented CPM and the number of generated segments The DF should include the following information: • totalMsgSegments: The total number of messages required on the transmitter side to distribute the information to several messages. It should be represented as defined in clause C.47 • thisSegmentNum: Indicates the number of the received message out of the total number of messages used to realize segmentation. It should be represented as defined in clause C.47
Unit	-

C.47 DE_SegmentCount

Descriptive Name	SegmentCount
ASN.1 representation	`SegmentCount ::= INTEGER(1..127)`
Definition	A number representing either the total number of generated segments by the transmitter or the identification of the received message segment
Unit	-

C.48 DE_NumberOfPerceivedObjects

Descriptive Name	NumberOfPerceivedObjects
ASN.1 representation	`NumberOfPerceivedObjects ::= INTEGER (0..255)`
Definition	A number representing the total number of detected and shared objects of an ITS-S transmitting a CPM
Unit	-

C.49 DF_FreeSpaceArea

Descriptive Name	FreeSpaceArea

ASN.1 representation	`FreeSpaceArea ::= CHOICE {`
	`    freeSpacePolygon     AreaPolygon,`
	`    freeSpaceCircular    AreaCircular,`
	`    freeSpaceEllipse     AreaEllipse,`
	`    freeSpaceRectangle   AreaRectangle`
	`}`

Definition	The described area that is considered as not occupied by any traffic participant or obstacle by the disseminating ITS-S The DF should include the following information: • freeSpacePolygon: a sequence of node points from a given offset point to describe an arbitrary area shape. It should be represented as defined in clause C.39 • freeSpaceCircular: description of a circular area. It should be represented as defined in clause C.38 • freeSpaceEllipse: description of an elliptical area. It should be represented as defined in clause C.37 • freeSpaceRectangle: description of a rectangular area. It should be represented as defined in clause C.36
Unit	-

C.50 DE_FreeSpaceConfidence

Descriptive Name	FreeSpaceConfidence
ASN.1 representation	`FreeSpaceConfidence ::= INTEGER {unknown(0), onePercent(1),` `oneHundredPercent(100), unavailable(101)} (0..101)`
Definition	Confidence indicating that an indicated area is not occupied by a traffic participant or obstacle. The value should be set to: • Unknown (0): if the free space confidence is unknown for the described area • A value between 1 and 100 to express the confidence for the described area • Unavailable (101): if the confidence could not be computed and does not apply
Unit	-

C.51 DF_ObjectClass

Descriptive Name	objectClass

ASN.1 representation	`ObjectClass ::= SEQUENCE {`
	`    confidence  ClassConfidence,`
	`    class    CHOICE {`
	`        vehicle                 VehicleSubclass,`
	`        person                  PersonSubclass,`
	`        animal                  AnimalSubclass,`
	`        other                   OtherSubclass`
	`    }`
	`}`

Definition	Describes the classification of a detected object. The object can be classified into one of five categories: unknown, vehicle, person, animal and other. The classification is performed with a certain confidence The DF should include the following information: • class: the class that best describes the detected object. Each class provides optional subclasses and an associated confidence for the subclass. The class should be set to one of the following – vehicle: the detected object is of type vehicle. It should be represented as defined in clause C.52 – person: the detected object is of type person. It should be represented as defined in clause C.54 – animal: the detected object is of type animal. It should be represented as defined in clause C.56 – other: the detected object is of another type. It should be represented as defined in clause C.59
Unit	-

C.52 DF_VehicleSubclass

Descriptive Name	vehicleSubclass

ASN.1 representation	`VehicleSubclass ::= SEQUENCE {`
	`    type        VehicleSubclassType DEFAULT 0,`
	`    confidence  ClassConfidence DEFAULT 0`
	`}`

Definition	Describes the subclass of a detected object for class vehicle. This DF should include the following information: • Type: the subclass type of the vehicle as defined in clause C.53 • Confidence: Confidence that the assigned sub-class applies, as defined in clause C.58
Unit	-

C.53 DE_VehicleSubclassType

Descriptive Name	vehicleSubclassType
ASN.1 representation	`VehicleSubclassType ::= INTEGER {unknown(0), moped(1), motorcycle(2), passengerCar(3), bus(4), lightTruck(5), heavyTruck(6), trailer(7), specialVehicles(8), tram(9), emergencyVehicle(10), agricultural(11)} (0..255)`
Definition	Describes the subclass of a detected object for class vehicle. It can be set to one of the following: • unknown (0): the type of vehicle is unknown • moped (1): the detected object is a light motor vehicle with less than four wheels as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class L1, L2 • motorcycle (2): the detected object is a light motor vehicle with less than four wheels as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class L3, L4, L5, L6, L7 • passengerCar (3): the detected object is a small passenger car as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class M1 • bus (4): the detected object is a large passenger vehicle as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class M2, M3 • lightTruck (5): the detected object is a light goods vehicle as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class N1 • heavyTruck (6): the detected object is a heavy goods vehicle as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class N2, N3 • trailer (7): the detected object is an unpowered vehicle that is intended to be towed by a powered vehicle as defined in UNECE/TRANS/WP.29/78/Rev.4 [i.36] class O • specialVehicle (8): the detected object is a vehicle which has a special purpose other than the above (e.g. moving road works vehicle) • tram (9): the detected object is a vehicle running on tracks along public streets • emergencyVehicle (10): the detected object is a vehicle used in an emergency situation such as an ambulance, police car or fire engine • agricultural (11): the detected object is a vehicle used for agricultural purposes
Unit	-

C.54 DF_PersonSubclass

Descriptive Name	personSubclass

ASN.1 representation	`PersonSubclass ::= SEQUENCE {`
	`    type        PersonSubclassType DEFAULT 0,`
	`    confidence  ClassConfidence DEFAULT 0`
	`}`

Definition	Describes the subclass of a detected object for the person subclass: • Type: The subclass type for persons, as defined in clause C.55 • Confidence: Confidence that the assigned sub-class applies, as defined in clause C.58
Unit	-

C.55 DE_PersonSubclassType

Descriptive Name	personSubclassType
ASN.1 representation	`PersonSubclassType ::= INTEGER {unknown(0), pedestrian(1), personInWheelchair(2), cyclist(3), personWithStroller(4), personOnSkates(5), personGroup(6)} (0..255)`
Definition	Describes the subclass of a detected object for class persons. Persons are a subset of the vulnerable road users as defined in clause 4.2 of [i.37] as well as in the classification provided in annex 1 of Regulation EU 168/2013 [i.38]. It can be set to one of the following: • unknown (0): the vru type for the detected object is unknown • pedestrian (1): the detected object is a pedestrian travelling on foot • personInWheelchair (2): the detected object is a person travelling in a wheelchair • cyclist (3): the detected object is one or multiple persons travelling on non-motorized unicycles, bicycles, tricycles or quadricycle • personWithStroller (4): the detected object is a person travelling on foot pushing or pulling a stroller potentially carrying by one or multiple other persons • personOnSkates (5): the detected object is a person travelling on skates, skateboards or a small electric or foot operated scooter • personGroup (6): the detected object is a group of persons with similar movement characteristics
Unit	-

C.56 DF_AnimalSubclass

Descriptive Name	animalSubclass

ASN.1 representation	`AnimalSubclass ::= SEQUENCE {`
	`    type        AnimalSubclassType DEFAULT 0,`
	`    confidence  ClassConfidence DEFAULT 0`
	`}`

Definition	Describes the subclass of a detected object for class animal. It can be set to one of the following: • Type: The subclass type for animal, as defined in clause C.57 • Confidence: Confidence that the assigned sub-class applies, as defined in clause C.58
Unit	-

C.57 DE_AnimalSubclassType

Descriptive Name	animalSubclassType
ASN.1 representation	`AnimalSubclassType ::= INTEGER {unknown(0)} (0..255)`
Definition	Describes the subclass of a detected object for class animal. It can be set to the following: • unknown (0): the kind of animal is not known
Unit	-

C.58 DE_ClassConfidence

Descriptive Name	classConfidence
ASN.1 representation	`ClassConfidence ::= INTEGER {unknown(0), onePercent(1), oneHundredPercent(100), unavailable(101)} (0..101)`
Definition	Describes the confidence value for the type of a detected object. The value should be set to: • unknown (0): in case the confidence value is unknown but the reported classification is still valid • a value between 1 and 100 representing the confidence that the provided class applies for the object • unavailable (101): in case the class confidence value computation is not available for this object. Indicates that the class assignment is invalid
Unit	-

C.59 DF_OtherSubclass

Descriptive Name	otherSubclass

ASN.1 representation	`OtherSubclass ::= SEQUENCE {`
	`    type        OtherSublassType DEFAULT 0,`
	`    confidence  ClassConfidence DEFAULT 0`
	`}`

Definition	Describes the subclass of a detected object for class other. This DF should include the following information: • Type: The subclass type for other, as defined in clause C.60 • Confidence: Confidence that the assigned sub-class applies, as defined in clause C.58
Unit	-

C.60 DE_OtherSubclassType

Descriptive Name	otherSubclassType
ASN.1 representation	`OtherSublassType ::= INTEGER {unknown(0), roadSideUnit(1)} (0..255)`
Definition	Describes the subclass of a detected object for class other. The value should be set to: • unknown (0): the detected object is of another class that is not defined • roadSideUnit (1): the detected object is a road side unit ITS-S
Unit	-

C.61 DF_SensorIdList

Descriptive Name	sensorIdList
ASN.1 representation	`SensorIdList ::= SEQUENCE SIZE(1..128, ...) OF Identifier`
Definition	Describes a list of sensor IDs. Each sensor ID is represented as defined by clause C.13
Unit	-

C.62 DF_NodeOffsetPointZ

Descriptive Name	nodeOffsetPointZ

ASN.1 representation	`NodeOffsetPointZ ::= CHOICE {`
	`    node-Z1 Offset-B10, -- node is within 5.11m of last node`
	`    node-Z2 Offset-B11, -- node is within 10.23m of last node`
	`    node-Z3 Offset-B12, -- node is within 20.47m of last node`
	`    node-Z4 Offset-B13, -- node is within 40.96m of last node`
	`    node-Z5 Offset-B14, -- node is within 81.91m of last node`
	`    node-Z6 Offset-B16  -- node is within 327.67m of last node`
	`}`

Definition	Describes the vertical offset from another point. This is specified in close resemblance to SAE J2735 [i.6]
Unit	-

C.63 DF_ShadowingApplies

Descriptive Name	shadowingApplies
ASN.1 representation	`ShadowingApplies          ::= BOOLEAN`
Definition	Boolean indicator to indicate if tracing approach should be used to compute a shadowed area behind an object. If set to TRUE, the simple tracing approach should be applied for each object intersecting or located within the area or volume described by the freeSpaceAddendum container. If set to FALSE, the simple tracing approach should not be applied for each object intersecting or located within the area or volume described by the freeSpaceAddenum container
Unit	-

Annex D: CPM Generation Rule

This annex provides an exemplary implementation for the CPM generation rule defined in clause 4.3. The design includes four major sub-processes as shown in Figure D.1. These processes are connected in a master diagram illustrating the steps of composing a CP message. The first three sub-processes illustrate how to populate the *Perceived Object Container* (Figure D.2), the *Sensor Information Container* (Figure D.3) and the *Station Data Container* and the *Management Container* (Figure D.4) of a CPM. The fourth sub-process (Figure D.5) shows an examplary algorithm for CPM segmentation once the size of the message exceeds a predefined threshold.

The master diagram depicted in Figure D.1 is executed no faster than every *T_GenCpm* which may be adapted by the DCC algorithm to prevent channel overuse, as outlined in clause 4.3. If neither a *Perceived Object Container* nor a *Sensor Information Container* are generated by following the detailed sub-processes, no CPM is generated in the current cycle. In the case that a CPM is generated, a station data and management container is included. A segmentation check algorithm is then performed to determine if message segmentation is required.

Figure D.2 details the sub-process to identify and populate the perceived object candidates for a CPM to be transmitted. It implements the first four CPM triggering conditions as defined in clause 4.3.

Figure D.3 describes the algorithm for generating the *Sensor Information Container*. Note that this container is included in a CPM independent of inclusion of the *Perceived Object Container*. As stated in clause 4.3, in case no object is detected with sufficient confidence, an ITS-S still needs to generate CPMs periodically to report that it is equipped with local perception sensors but is currently not perceiving any objects within its perception range.

The process for assembling the *Station Data Container* and the *Management Container* is detailed as part of the sub-process depicted in Figure D.4. An originating ITS-S can be either a RSU or a vehicle which has different station containers. The depicted process then assembles a CPM with all generated containers up to this point, potentially including the *Sensor Information* and *Perceived Objects Container.* In case the resulting message size after including all perceived object candidates exceeds *MTU_CPM* for the given access layer technology, message segmentation should occur.

In case the CP message needs to be segmented as a result of exceeding the allowed size of *MTU_CPM*, perceived object candidates are added to the CPM segment until either all objects are included or the message size exceeds the *MTU_CPM*, as depicted in Figure D.5. The object selection process thereby takes the previously generated *Station Data* and *Management Container* into account, when computing the resulting message size. Once the object candidates for the current segment are identified, it is checked whether the *Sensor Information Container* can also be added without violating the message size constraint of *MTU_CPM*. Otherwise, this process is repeated and more CP Message segments are generated until all perceived object candidates and the *Sensor Information Container* is in included in a CPM segment.

Once the CPM (or CPM segments) are generated, it is returned to main process *Generate CPM* which then updates the timestamp corresponding to this generation event and passes the message(s) to the lower layer for transmission.

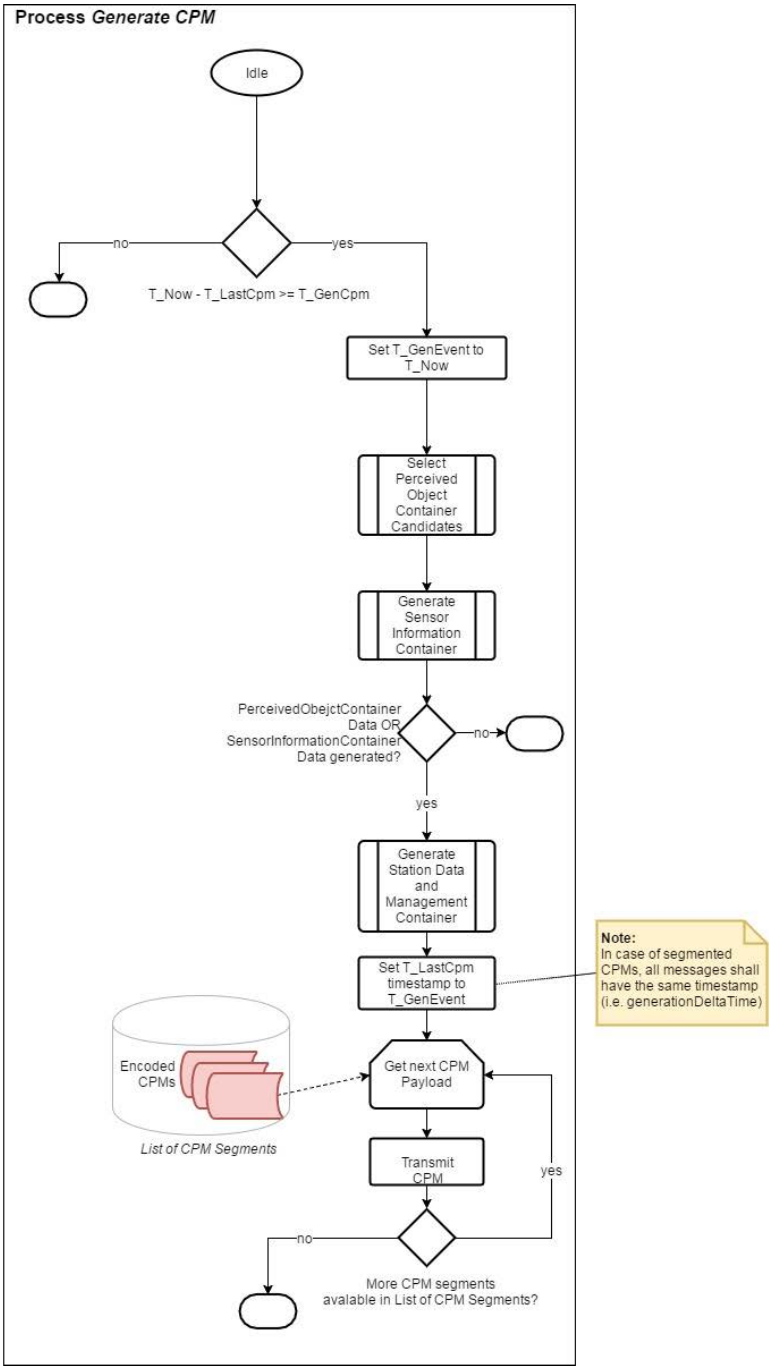


Figure D.1: Process Generate CPM

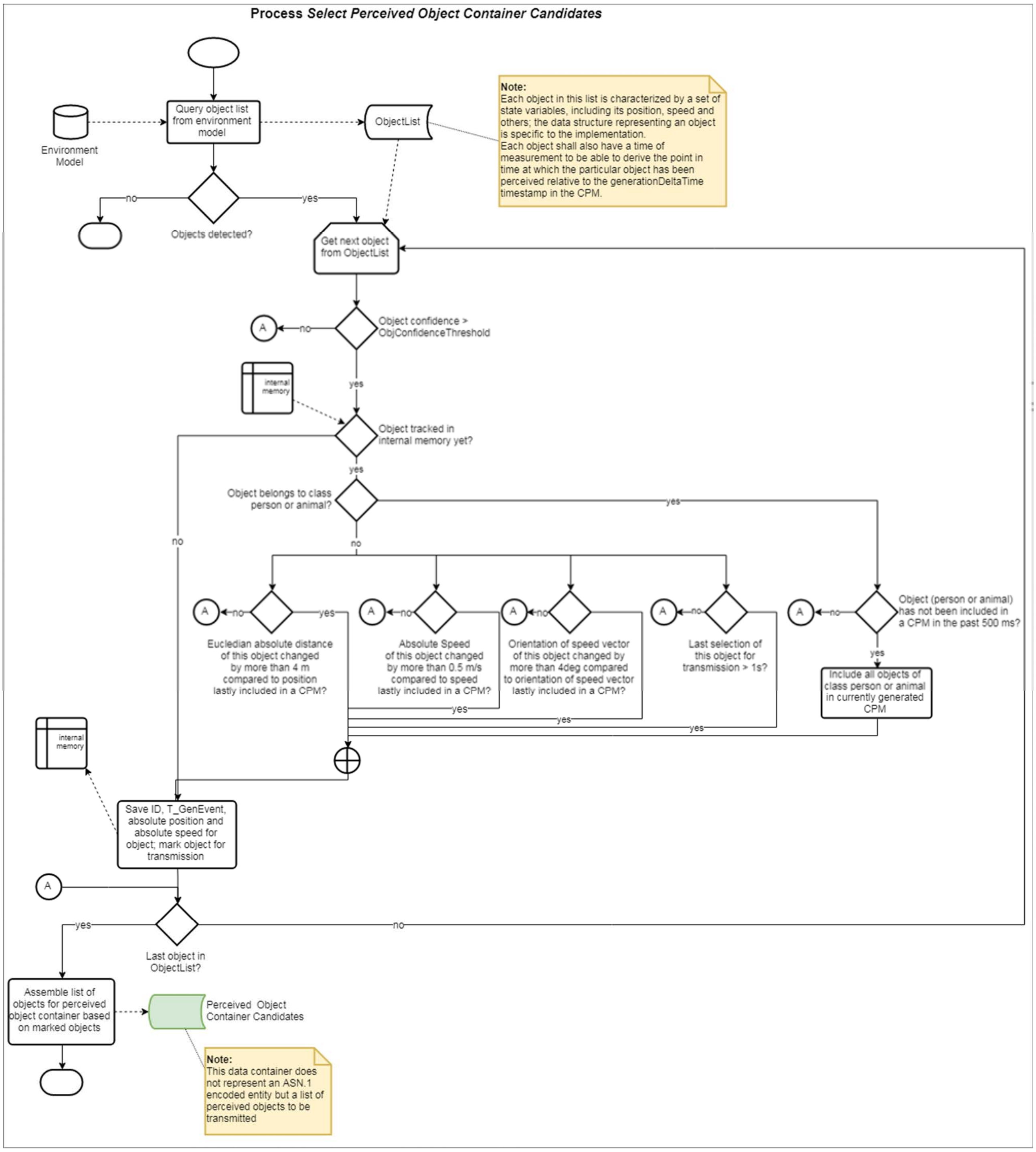


Figure D.2: Process Select Perceived Object Container Candidates

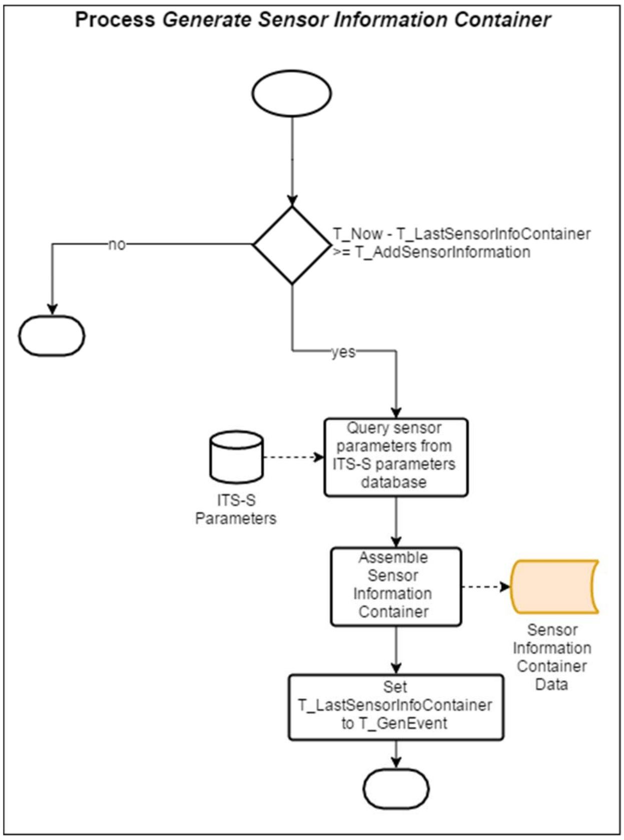


Figure D.3: Process Generate Sensor Information Container

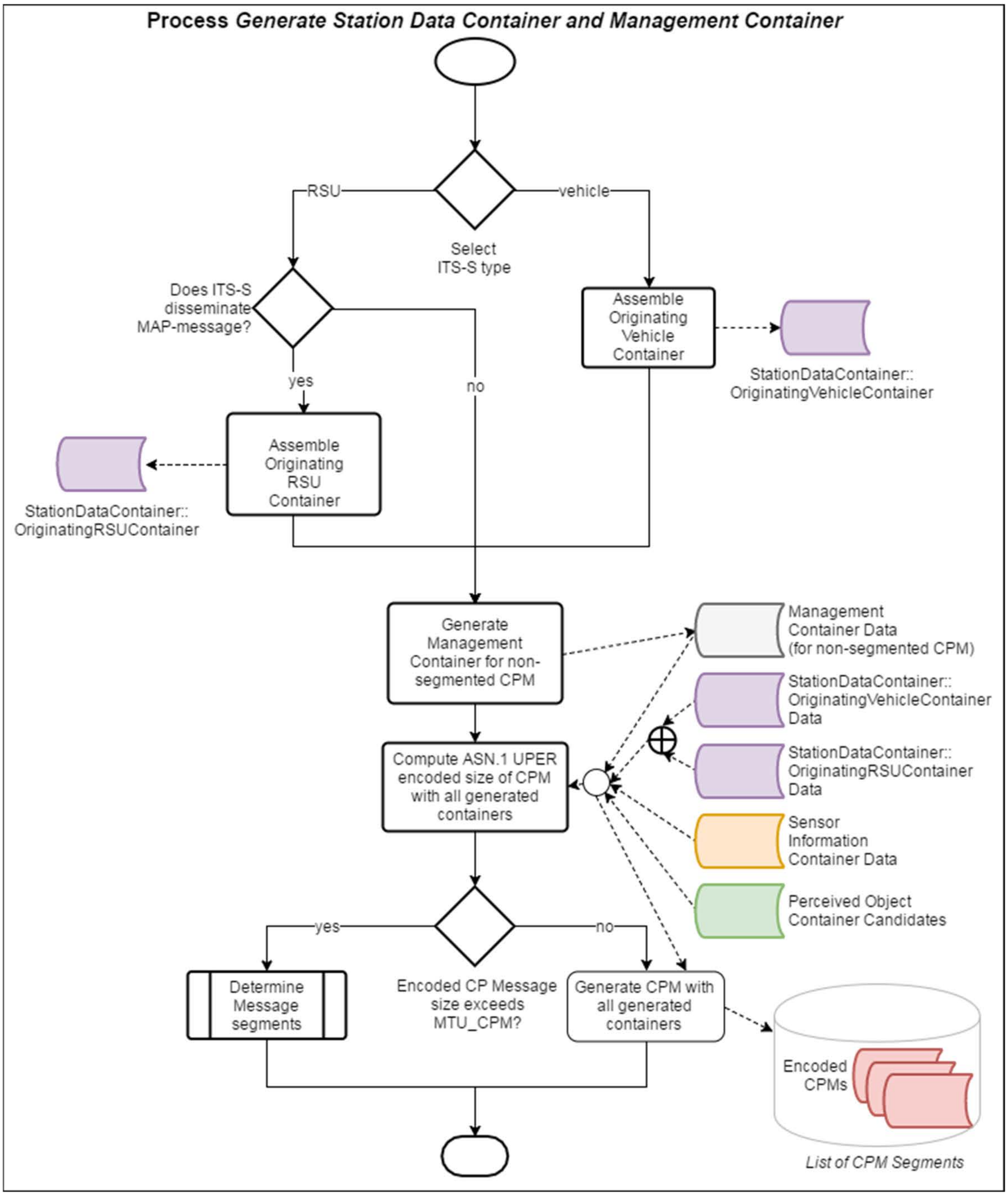


Figure D.4: Process Generate Station Data Container and Management Container

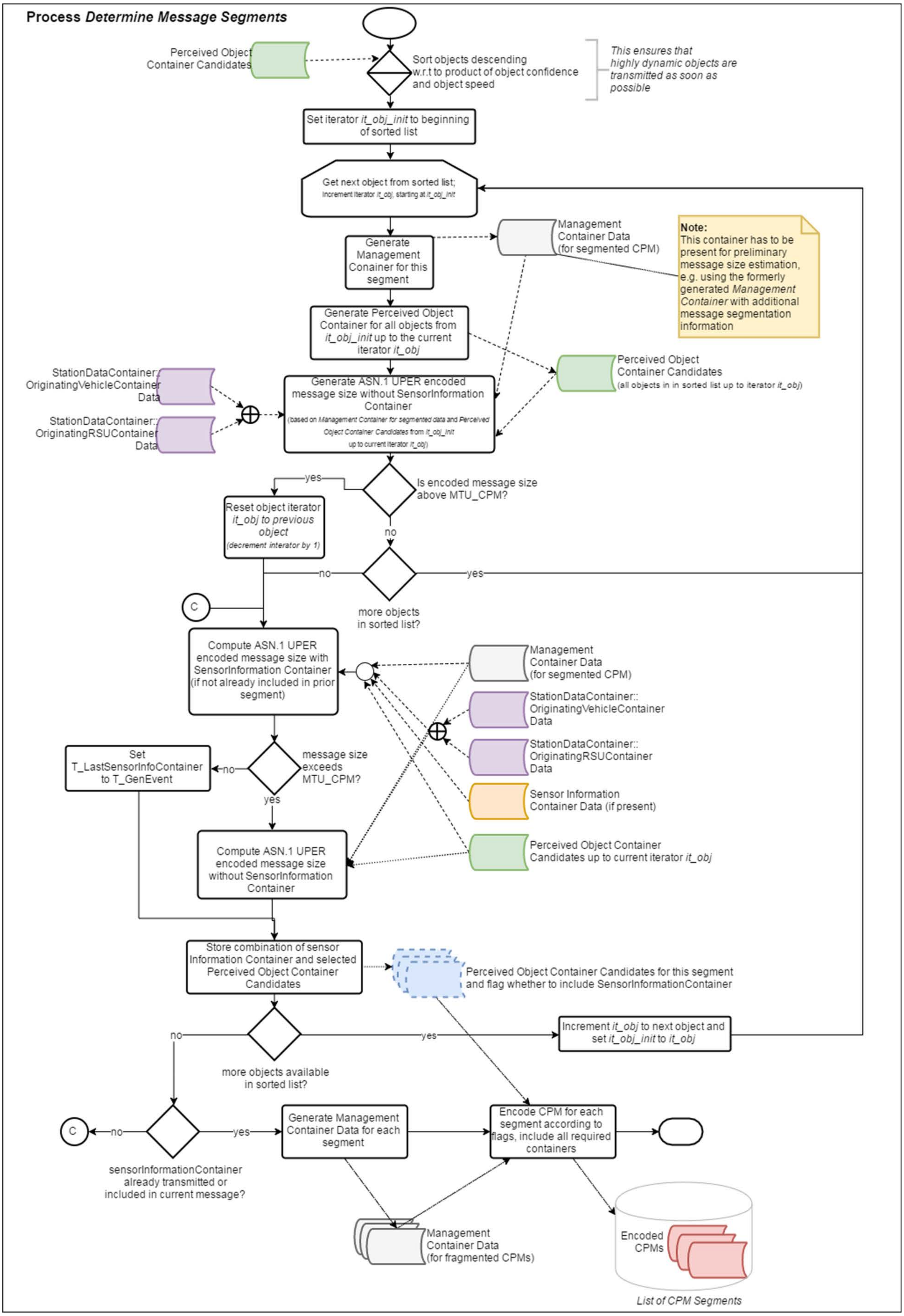


Figure D.5: Process Determine Message Segments

Annex E: Change History

Date	Version	Information about changes
August 2017	0.0.1	First presentation in drafting session 2017-08-31
October 2017	0.0.5	Integration of discussion items from August Drafting Session; Proposal of objects to include and Notification of updated
April 2018	0.0.7	Consolidated Message Format added to Report along with preliminary descriptions of all data fields in Appendix
May 2018	0.0.8	Use-case Section introduced, stationDataContainer set as optional (ASN.1 and description update), removed obsolete descriptions after update of Section 5
June 2018	0.0.9	Message structure updated
June 2018	0.0.10	Use-cases introduced. Time of measurement figure included
September 2018	0.0.12	Use-cases updated, message format reviewed and bugs fixed
October 2018	0.0.13	Update Message format with ASN.1 definitions for classification, description missing. Further changed TR to new ETSI skeletons
October 2018	0.0.14	Update Message format after October drafting session. Added further classification options and renamed segmentation variables
January 2019	0.0.15	Message refinements, include reference in message to ETSI EN 302 637-2, unified variable names. Included message generation rules. Finalized Use Case descriptions
June 2019	0.0.16	Clause 4: Generation Rules and dissemination concept updated based on concept developed in Annex D Clause 5: Results of simulation studies added and described Clause 6: Updated description of message format and inclusion of free space description Anexes A-C: Message format updated to include FreeSpaceDescription
September 2019	0.0.17	Clause 4: Revised Generation Rules based on multiple drafting sessions, introduced special VRU handling; inserted data redundancy mitigation techniques Clause 5: Included simulation results for "look-ahead mechanism" Clause 6: Revise description of free space container; Introduction of "FreeSpaceAddendum" Concept
September 2019	0.0.18	Minor typo fixes, aligned version for final draft publication
September 2019	0.0.19	Added further redundancy mitigation techniques; minor wording and punctuation changes
October 2019	0.0.20	Editorial changes in preparation for Final Draft for Approval release

History

Document history		
V2.1.1	December 2019	Publication