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ENabling **S**af**E** **M**ulti-**B**rand p**L**atooning for **E**urope

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EXECUTIVE SUMMARY

Context

Platooning technology has made significant advances in the last decade, but to achieve the next step towards deployment of truck platooning, an integral multi-brand approach is required. Aiming for Europe-wide deployment of platooning, 'multi-brand' solutions are paramount. It is the ambition of ENSEMBLE to realise pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonisation of legal frameworks in the member states.

Project scope

The main goal of the ENSEMBLE project is to pave the way for the adoption of multi-brand truck platooning in Europe to improve fuel economy, traffic safety and throughput. This will be demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders. During the years, the project goals are:

- Year 1: setting the specifications and developing a reference design with acceptance criteria
- Year 2: implementing this reference design on the OEM own trucks as well as perform impact assessments with several criteria
- Year 3: focus on testing the multi-brand platoons on test tracks and international public roads

The technical results will be evaluated against the initial requirements. Also, the impact on fuel consumption, drivers and other road users will be established. In the end, all activities within the project aim to accelerate the deployment of multi-brand truck platooning in Europe.

Abstract of this Deliverable

This deliverable provides a specification of the V2X communication protocol to enable platooning using the wireless communication standard ITS-G5. The protocol specifies how vehicles inform each other about their ability to form a platoon, and which data has to be exchanged when executing the actual procedure of joining, driving in the platoon and leaving a platoon. It includes messages and how to exchange them to allow for the aforementioned situations.

In ENSEMBLE, a new facilities layer protocol supporting the platooning application is developed. This makes use of already standardized lower layer protocols in ETSI TC ITS. The platooning protocol uses already available message types and signals, and where necessary new ones are introduced. The protocol logic for joining, platooning, and leaving has been derived from the use cases in deliverable D2.2 of ENSEMBLE. The available security framework for cooperative intelligent transport system (C-ITS) in Europe is used for signing and verifying unencrypted messages to establish a trust domain. In addition, the security is extended with encryption of platoon application data using symmetric keys. Deliverable 2.9 will specifically treat security in platooning.

It should be noted that parts of this deliverable might be subject to changes such as the specification of messages, data elements, and the security approach.

1. INTRODUCTION

Cooperative Intelligent Transport Systems (C-ITS) refers to applications using wireless communication between vehicles, vehicle-to-vehicle communication (V2V), and between vehicles and smart road infrastructure, vehicle-to-smart road infrastructure communication (V2I), for increasing road traffic safety and efficiency. V2V and V2I communications are collectively known as V2X communication. Present document specifies a facilities layer protocol for supporting truck platooning using the wireless technology ITS-G5 (a.k.a. IEEE 802.11p [9]/WLANp) at 5.9 GHz band.

Direct communication between vehicles and between vehicles and smart infrastructure has the potential to save lives and reduce the environmental impact. Frequency bands for V2X were allocated in 2008 in Europe and already in 1999 in the US at a carrier frequency of 5.9 GHz. In Europe, standardization has been carried out in the EC acknowledged standards development organization (SDO) ETSI[1] and its Technical Committee on Intelligent Transport Systems (TC ITS). Pre-standardization and deployment issues are treated in CAR 2 CAR Communication Consortium[2] (C2C-CC), a non-profit organization collecting OEMs, suppliers, universities and research institutes. More information about ETSI's protocols and deployment plans are found in [1,2], respectively. It should be noted that the wireless technology IEEE 802.11p is also called ITS-G5 and WLANp in Europe. Standards are necessary to create an interoperabe system between different brands.

SAE[3] and IEEE[4] have created an interoperable V2X system in the US. SAE has focused on message sets for V2X and IEEE has developed all lower layer protocols. Crash Avoidance Metric Partnership (CAMP) has collected OEMs and CAMP has run several public funded research projects and conducted pre-standardization tasks. The wireless technology (IEEE 802.11p) is used both in Europe and in the US. An overview of the protocol stack in the US is found in [3].

Focus on standardization has been to increase the awareness horizon for the driver by alerting the driver about impending dangerous situations and then the driver needs to take appropriate action (no automated control of the vehicle based on received V2X data). A number of so-called day-one applications (or services) have been defined such as stationary vehicle warning, slow vehicle warning, emergency electronic brake light etc., by C2C-CC and further elaborated in the Commission work "C-ITS deployment platform" [16]. These day-one services are using two distinct facilities layer protocols developed by ETSI TC ITS called Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Message (DENM), where the former are always present triggered by vehicle dynamics containing information about the vehicle such as type, speed, position

[1] European Telecomunications Standards Institute, see http://www.etsi.org/
[2] CAR 2 CAR Communication Consortium, https://www.car-2-car.org/
[3] Society of Automotive Engineers, see http://www.sae.org/
[4] Institute of Electrical and Electronics Engineers, see https://www.ieee.org/

and heading. DENMs are only triggered on behalf of a dangerous situation and contains information about the dangerous event itself. The V2X communication is closing the gap between line-of-sight (LOS) sensors such as camera, lidar and radar, and the long-range cellular technology, by providing the possibility to see beyond physical barriers within milliseconds.

In platooning and cooperative adaptive cruise control (C-ACC) belong is V2X data one sensor input together with other sensor data such as radar and camera for controlling the vehicle laterally and longitudinally automatically. Platooning and C-ACC are regarded as safety applications as well as efficiency applications. C-ACC can mitigate shockwaves through traffic and thereby, avoid rear-end collisions but at the same time increase the number of vehicles on the roads without increasing congestion.

Platooning can make today's spontaneous platooning safer (trucks are already today driving too close without help from technology, violating regulation and safety) and support the driver in the monotonous task of driving in a highway environment by alerting the driver about impending hazardous events. The first truck in a platoon sees further ahead using conventional line-of-sight (LOS) technologies (radar and camera), and when the first truck detects any anomalies it will inform the other trucks in the platoon facilitating orchestrated braking for example. Regardless of distances between the trucks, a truck using only conventional radar cannot see beyond physical barriers, by adding the V2X component the driving of trucks will be made safer since the first truck can inform other trucks behind it about dangerous situations. And of course, from a fuel economy perspective less jerky driving and reduced air drag due to decreased distances between the trucks will reduce the environmental impact due to fuel consumption reduction.

1.1. Purpose

The purpose of this deliverable is to define a facilities layer protocol supporting platooning. The protocol consists of logic, new message and data types along with added security (encryption of messages) to enable a pan-European multibrand platooning system.

1.2. Scope

This deliverable describes the protocol logic, message sets, data formats and security, for enabling platooning on public roads using IEEE 802.11p/ITS-G5 communication on a carrier frequency of 5.9 GHz. (This deliverable does not address cellular communication for accessing a back-office system.)

1.3. Outline

Chapter 2 provides information about already standardized protocols that will be used by the ENSEMBLE project. Further, in Chapter 3, detailed parameter settings of the standardized protocols are provided. The ENSEMBLE platooning protocol is detailed in Chapter 4 and a summary is outlined in Chapter 5. References are provided in Chapter 6. At the end of the deliverable two appendices outlining ASN.1 structure of messages and abbreviations are provided.

2. V2X STANDARDIZED PROTOCOL STACK

2.1. Overview of already standardized protocols

Protocols have been developed in ETSI TC ITS[5] to achieve interoperability between different brands supporting day-one applications. Protocols are organized into layers to break down the complexity of communication, i.e., protocol stacks. Two distinct protocols in the facilities layer support traffic safety, the ubiquitous position messages (called cooperative awareness message, CAM) and the event-triggered hazard warnings, which are only present as long as the event is valid (called decentralized environmental notification message, DENM). Triggering conditions for DENMs have been developed by C2C-CC. In Figure 1, the C-ITS protocol stack is depicted. The platooning protocol developed in ENSEMBLE is situated at the facilities layer, see Figure 1, and it shares the same lower layer protocols as for transmitting CAMs and DENMs. The platooning capability of a vehicle, will be announced in existing CAMs by extending the CAM with a platooning container.

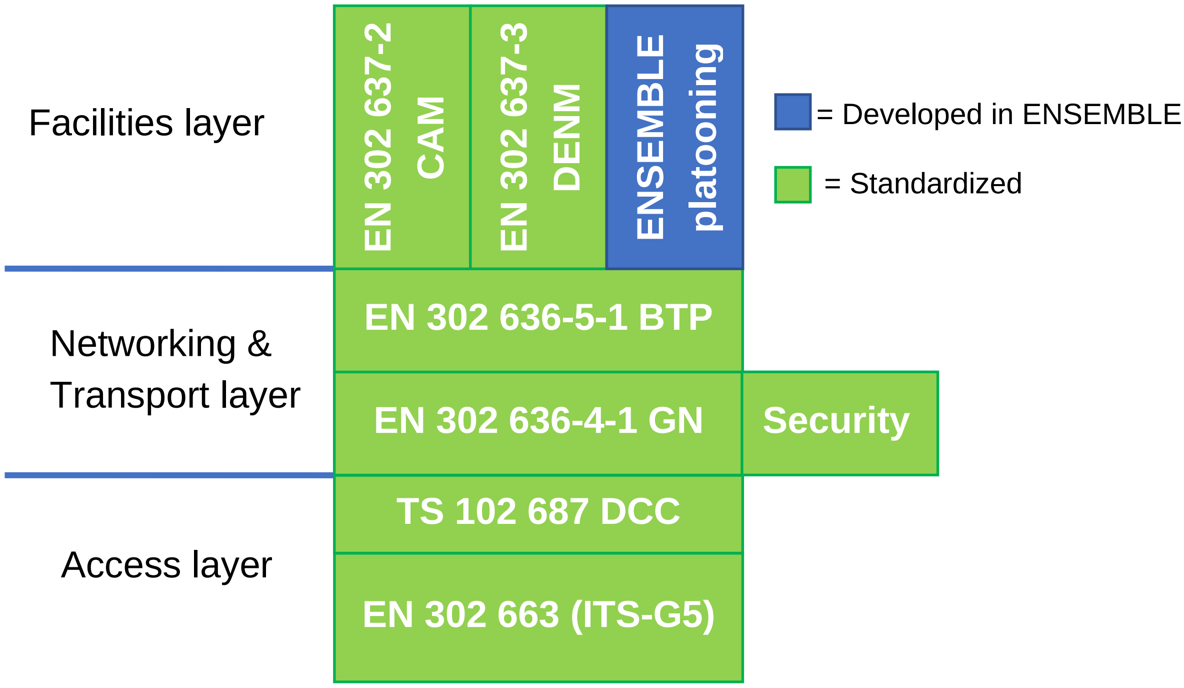

Figure 1: C-ITS protocol stack with standardized protocols and the ENSEMBLE platooning protocol

All dissemination of CAMs and DENMs is broadcast communication, implying that no session or similar is established between communicating parties. Broadcast communication has been selected because no sessions can be created due to highly dynamic networks and vehicles can move in and

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[5] European Telecommunications Standards Institute (www.etsi.org), consists of several technical committees (TC) treating communication in different areas, TC on Intelligent Transport Systems (TC ITS), was established in December 2007, to address the interoperability between vehicles and vehicles and smart infrastructure. EC issued mandate M/453 to accelerate the standardization process in 2008.

out of each others communication ranges quickly. Further, no acknowledgments are transmitted if packets are received successfully. However, nothing prevents from having session-based applications such as platooning. Focus on standardization of the C-ITS protocol stack has been on broadcasting CAMs and DENMs, and it is up to every OEM to digest these and display appropriate information to the driver (i.e., the driver is responsible for taking appropriate action based on displayed warnings). In other words, C-ITS day-one applications aim at extending the information horizon of the driver and it is on the receiving side where competition between brands will take place. All approved ETSI standards are available for free download on the Internet.

The facilities layer protocols CAM and DENM are mainly executed on the vehicle but also other protocols only residing on smart infrastructure are also possible to support such as MAP, which transmits the outline of an intersection, and SPAT (Signal, Phase and Timing) informs vehicles approaching red lights about the next green phase. Day-one services, based on the facilities layer protocols CAM, DENM, MAP and SPAT, and platooning will co-exist in C-ITS. This implies that vehicles capable of platooning will also implement and receive information about upcoming dangerous situations, DENM reception, (stationary vehicle warning, slow vehicle warning, road works warning etc) and next green phase at red lights (green light optimal speed advisory). Thus platooning enabled trucks will also do day-one services.

Security will be treated in Deliverable 2.9 and the approach elaborated in Chapter 3 and Chapter 4 might be subject to changes. In short, the platooning protocol will be part of the public key infrastructure (PKI) developed for C-ITS where messages are signed and verified using a temporarily authorization ticket. In addition, the platooning control messages will also be encrypted using symmetric keys.

The ENSEMBLE platooning protocol will be specified in Chapter 4 in present deliverable and it will support the platooning application, which is fusing information from several sources in order to control the vehicle in a safe way in the platoon.

In the following subchapters, already standardized protocols used in the ENSEMBLE project will be briefly outlined. Chapter 3 will provide a parameter setting of the standardized protocol stack.

2.2. EN 302 663 access layer technology ITS-G5

EN 302 663 V1.2.1 [4] defines the access layer technology (access layer consists of the physical and datalink layer in the OSI model). The access layer technology outlined in EN 302 663 is IEEE 802.11p[6], which defines the physical layer and the sublayer medium access control (MAC) together with the logical link control (LLC) protocol, IEEE 802.2. LLC provides means of differentiating

[6] IEEE 802.11p is superseded and it is no longer a standalone amendment to IEEE 802.11. It was enrolled in the legacy standard IEEE Std 802.11-2012. But for simplicity the notion of IEEE 802.11p will be used throughout the document. An IEEE 802.11p equipped vehicle operates outside the context of a basic service set (BSS) and this is enabled through `dot11OCBActivated` set to TRUE.

between network layer protcools (e.g., geonetworking, internet protocol, IP). EN 302 663 V1.2.1 [4] was approved and published in 2012 and it has just recently been opened for revision because it contains flaws and things have changed since 2012. Specifically, Clause 4.2 and Clause 4.3 of EN 302 663 V1.2.1 [4] addressing frequency channels are not correct and will be removed. EN 302 571 V2.1.1 [5] contains the necessary information regarding the frequency allocation.

For the interested reader, Annex B of EN 302 663 V1.2.1 [4] contains a description of IEEE 802.11p and how it differs from traditional WiFi networking. Further, it describes the MAC procedure for broadcast and the 4 different priorities (queues) provided for Quality of Service (QoS).

EN 302 663 V1.2.1 [4] refers normatively to TS 102 687 V1.1.1 [6], addressing decentralized congestion control (DCC), and TS 102 792 V1.1.1 [7] addressing co-existence with CEN DSRC. Both these standards have been revised and new versions have been published, which will be described in Clause 2.3 TS 102 687 DCC and Clause 2.9.4 Co-existence with CEN DSRC. The old versions are perceived as deprecated.

2.3. TS 102 687 DCC

TS 102 687 V1.1.1 [6] has been superseded by a new version V.1.2.1 [8]. This standard treats decentralized congestion control (DCC) with the aim of controlling the network load in situations when there are many ITS stations within radio range wanting access to the shared frequency channel. DCC is not a necessity to achieve interoperability between different brands but merely to specify a common behaviour once the channel busy ratio (CBR) will increase when many ITS stations in the same geographical area want to access the channel. The purpose of the DCC is to have graceful and predictable performance degradation of ITS applications at large when the CBR increases. This is achieved by each and every ITS station executing suitable DCC algorithms. The new version of TS 102 687 (V1.2.1) provides two different algorithms – adaptive and reactive – where the former is introduced in this version.

The adaptive approach was introduced to combat the drawbacks with the reactive approach, where ITS stations experience fluctuating number of transmission opportunities from time to time when the DCC algorithm is executed. The oscillating behaviour has been identified by several research articles. The adaptive approach is a closed-loop where the CBR value is fed back to the controller. This in comparison to the reactive being an open-loop control.

2.4. EN 302 636-4-1 GN

The GeoNetworking (GN) protocol resides in the networking and transport layer. It supports four different communication scenarios: point-to-point, point-to-multipoint, GeoAnycast, and GeoBroadcast, and to facilitate these, geographical addressing and forwarding are the key concepts. The addresses used for forwarding packets among ITS stations are based on geographical positions of the ITS stations and the forwarding itself is relying upon that each and every station has a perception of its part of the network, in other words, the nearest neighbors of the ITS station and their positions. The ego ITS station does not maintain a traditional routing table instead it keeps a list of neighbors it can currently can hear (receive packets from) and based on the geographical address of an incoming packet, the station forwards the packet if suitable. With GeoNetworking packets can be addressed to certain geographical regions of interest without knowing if there are ITS stations in the destination area or not.

Defined day-one applications (services) are predominantly one-hop broadcast communication and some of the geographical addressing schemes require high penetration rates of co-located ITS-G5 equipped vehicles. The GeoNetworking protocol is spread over several standards and in Table 1 these are outlined. However, the main standard to reach interoperability between vehicles is ETSI EN 302 636-4-1 V1.3.1, describing the different fields of the GeoNetworking (GN) header and applicable settings. This standard is “media-independent functionality” implying that it disregards what radio technology that is used. There is also a “media-dependent functionality” standards outlined in ETSI TS 102 636-4-2 that can be used for, e.g., disseminating CBR values between ITS stations. This TS is tailored towards ITS-G5.

Table 1: Overview of the GeoNetworking standards series

Standard	Name	Description
EN 302 636-1 V1.2.1	Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; **Part 1: Requirements**	Describes the functional requirements in GeoNetworking.
EN 302 636-2 V1.2.1	Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; **Part 2: Scenarios**	Describes different communication scenarios such as traditional point-to-point and point-to-multipoint scenarios as well as GeoBroadcast and GeoAnycast supported by GeoNetworking.
EN 302 636-3 V1.2.1	Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; **Part 3: Network Architecture**	Describes the different componets within the GeoNetworking architecture.
EN 302 636-4-1 V1.3.1	Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; **Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 1: Media-Independent Functionality**	The GeoNetworking protocol used when transmitting data. Defines packet types for the different communication modes.
TS 102 636-4-2 V1.1.1	Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; **Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 2: Media-dependent functionalities for ITS-G5**	Specifies DCC mechanisms at the network layer when the access technology ITS-G5 is used.

2.5. EN 302 636-5-1 BTP

BTP (Basic Transport Protocol) is a connectionless transport protocol specifically developed within ETSI to support low overhead communications and it adds a 4-byte header to the incoming protocol datagram unit (PDU) from the layer above. BTP multiplexes between different services found at the layer above by using port numbers in the same way as the transmission control protocol (TCP) and user datagram protocol (UDP) on the Internet do.

2.6. EN 302 637-2 CAM

Cooperative Awareness Messages (CAM) are always present, triggered based on vehicle dynamics with 1-10 Hz (1-10 times per second). For example. If the vehicle is driven above 140 km/h then it will transmit 10 CAMs per second (10 Hz). If the vehicle is stuck in a traffic jam, it will transmit with 1 Hz. The CAM contains the position, heading, speed of the vehicle amongst other things. By receiveing CAMs, the vehicle can detect approaching vehicles not yet seen by the driver or line-of-sight sensors such as radar and camera.

2.7. EN 302 637-3 DENM

Decentralized Environmental Notification Messages (DENM) are triggered on behalf of an ITS application when a dangerous situation is detected by other in-vehicle sensors. They contain information about the event itself but as well speed, heading, position and they will only be transmitted when the event is still valid. DENMs can be transmitted with 1-20 Hz.

2.8. Security – TS 103 097

ETSI Technical Specification (TS) 103 097 V1.3.1 “Intelligent Transport Systems (ITS); Security; Security header and certificate formats” specifies the onboard security and the format of the added signature and so forth to reach interoperability between different vehicles. As mentioned earlier, security is subject to its own deliverable (D2.9) since platooning will extend the already available PKI framework by inluding symmetric encryption of platooning data.

2.9. EN 302 571

2.9.1. Introduction

Harmonized EN 302 571 V2.1.1 [5] is the only standard that needs to be fulfilled to put wireless equipment operating at the 5.855-5.925 GHz band on the European market. It outlines radio related requirements on the transceiver itself such as output power, spectrum mask, spurious emission limits, etc., but it put also up requirements on duty cycle and co-existence with CEN DSRC, see Clause 2.9.4.

2.9.2. Frequency channels

During the revision of EN 302 571 leading to the approved and referenced version V2.1.1, all names on separate frequency channels and frequency bands were removed. EN 302 663 V1.2.1 [4] (describing the access layer technology called ITS-G5 for the 5.9 GHz band) still contains the names of the frequency bands (ITS-G5A, ITS-G5B and ITS-G5C) and the names of the frequency channels (CCH, and SCHx) but these will be removed when updating EN 302 663. In Figure s, the frequency band together with corresponding documentation for the designation of the frequency band is depicted. The IEEE channel numbers found in Figure 2 are stemming from a standardized way of referring to the frequency channels in the 5-6 GHz frequency band (see Clause 17.3.8.4.2 of IEEE 802.11-2016 [9]).

The commission decision 2008/671/EC states that 30 MHz shall be allocated in all EU member states for traffic safety related services. None of the documents regulating the 5.9 GHz band found in Figure 2, specifies a wireless technology to use. EN 302 571 cannot mandate a technology either. All wireless technologies fulfilling EN 302 571 can enter the frequency band.

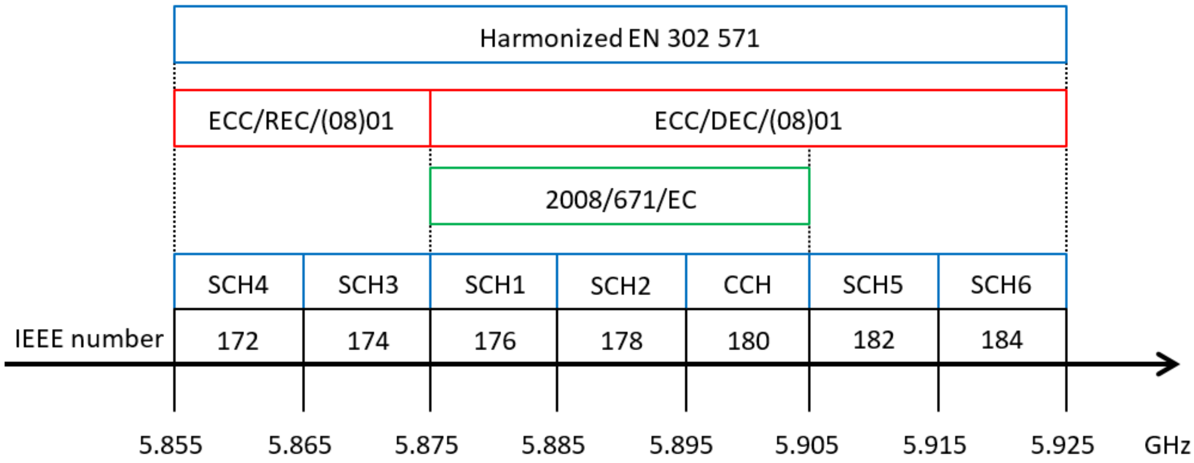

Figure 2: ITS frequency band in Europe with corresponding channel names and IEEE channel numbering

2.9.3. Duty cycle requirements and congestion control

EN 302 571 outlines the maximum allowance for each ITS station to use the channel. The duty cycle is set to 3% over a one second period, implying that 30 ms can be used by a single ITS station during one second. However, the 30 ms cannot be used consecutively, the maximum packet duration (T_{on}) is set to 4 ms and the time between two packets must be 25 ms (a.k.a. T_{off}), implying that if max T_{on} is used the channel can be accessed a maximum of 7 Hz. Thus, small T_{on} will result in more channel access possibilities per second and large T_{on} in fewer number of channel access. This is valid until a channel busy ratio (CBR) of 62% is reached. Then an equation kicks in increasing the duty cycle of 3%. EN 302 571 does not outline a specific DCC algorithm to be used but merely provides the limit that possible DCC algorithms need to adhere to.

NOTE: When an ITS station perceives a CBR of 60%, then there are approx. 1200 packets/s in the air given 400 byte packets transmitted with 6 Mbps. At around 2000 packets/s, a CBR of 100% is reached.

2.9.4. Co-existence with CEN DSRC[7]

EN 302 571 also puts up requirements on co-existence with CEN DSRC, which is used for collecting electronic toll (ETC) in free flow passages in Europe. It is based on a simple radio frequency identification (RFID) technology, where the onboard unit (OBU) in the vehicle is based on backscatter technology and the roadside unit (RSU) is emitting much energy to wake the OBU up. The OBU is only responding to incoming requests from the RSU and the network topology is centralized and the OBU cannot be used for anything else then ETC.

ITS-G5 equipment operating at 5.9 GHz will disturb the sensitive ETC transactions when there are many ITS-G5 equipped vehicles in the vicinity of an ETC plaza. And since ETC is a big business collecting a lot of money for road operators, the ETC business was concerned with the introduction of ITS-G5. When an ITS-G5 equipped vehicle approaches a toll plaza, it needs to adapt its number of transmissions and output power depending on the number of ITS-G5 equipped vehicles in the close vicinity of the plaza. However, this requirement on co-existence with CEN DSRC is only restricting ITS-G5 equipped vehicles in close vicinity of toll plazas. Everywhere else, transmissions and output power are restricted by EN 302 571 (duty cycle requirements) and DCC.

The technical requirements for co-existence with CEN DSRS are outlined in TS 102 792 V1.2.1 [10] (which is normatively referred to in EN 302 571). This TS outlines in essence, two different technical approaches to detect an ETC plaza (and when approaching the plaza countermeasures need to be performed to not disturb CEN DSRC):

1. Carry a database onboard the ITS-G5 equipped vehicle containing the placement of all toll plazas in Europe.
2. Include a CEN DSRC detector in the ITS-G5 hardware to detect when approaching a toll plaza. If a toll plaza is detected, the detecting vehicle needs to include information about the toll plaza in upcoming cooperative awareness messages (CAM) to alert other vehicles using a CEN DSRC detector (i.e., vehicles using the database do not need to react on CAMs transmitted from vehicles alerting about toll plaza).

There is an option for new installations of toll plazas to broadcast information using ITS-G5 for alerting vehicles approaching a toll plaza and all vehicles need to adhere to this information (regardless if the vehicle is using option 1 or option 2 above). Once an identification of a toll plaza is made, then countermeasures in terms of fewer transmission and reduced output power will be done depending on the number of C-ITS equipped vehicle in the vicinity. See TS 102 792 for full technical details [10].

[7] CEN DSRC should not be mixed up with DSRC technology in the US, where the latter equals IEEE 802.11p (ITS-G5). CEN DSRC will also be used for the upcoming European legislations on smart tachograpgh (Regulation (EU) No. 165/2014) and weight and dimension (Directive (EU) 2015/718) for road checks to substitute manual inspection in certain situations.

3. PARAMETER SETTINGS OF STANDARDIZED PROTOCOLS AND RADIO

3.1. Introduction

This chapter provides parametrization of standardized protocols and radio settings for ENSEMBLE. DENM triggering of day-one applications (services) will not be required in the ENSEMBLE project but individual vehicles might have the capability of receiving and transmitting DENMs.

REQ001: No specific triggering of DENMs will be implemented in ENSEMBLE.

3.2. Decentralized Congestion Control

The DCC algorithm adapts to the current CBR value and shapes the data traffic that the ego vehicles wants to transmit. The CBR is the best possible feedback currently available for understanding the status of the communication channel. DCC is not necessary to reach interoperability between vehicles. The adaptive approach in TS 102 687 V1.2.1, is applicable to platooning since it has graceful degradation of performance and will not result in major differences in transmission opportunities in between CBR assessments (important to avoid oscillations in transmission opportunities).

In the ENSEMBLE project, it is very unlikely that the CBR will increase to levels where the DCC needs to be in place to shape the data traffic. Therefore, it is decided that ENSEMBLE will not implement and evaluate any DCC algorithm since this will not be activated due to very low CBR values. But DCC needs to be investigated for platooning.

REQ002: No DCC will be implemented in ENSEMBLE.

3.3. EN 302 571

EN 302 571 puts up requirements on radio related parameters such as output power, and in addition also on duty cycle and co-existence with CEN DSRC.

The default output power selected for CAM/DENM disseminations in Europe based on the C2C-CC profile is 23 dBm e.i.r.p., implying the power leaving the antenna accounting for antenna gains, cable losses, and radio chipset. ENSEMBLE will use the same output power.

REQ003: The output power is set to 23 dBm e.i.r.p.

The duty cycle requirements are outlined in Clause 4.2.10 of EN 302 571 V2.1.1, where the overall duty cycle is set to 3% over a one second period.

REQ004: The ENSEMBLE platooning communication system needs to follow the duty cycle requirements outlined in Clause 4.2.10 of EN 302 571 V2.1.1.

Co-existence with CEN DSRC implies that the ITS station needs to be aware of upcoming electronic toll collection (ETC) zones in Europe, which are using a carrier frequency of 5.8 GHz. When in a tolling zone, the ITS station needs to adhere to the rules set out in TS 102 792 V1.2.1 and this standard is normatively referred to from EN 302 571 V2.1.1.

REQ005: The ENSEMBLE platooning communication system needs to implement the database solution found in TS 102 792 V1.2.1.

3.4. Multi-channel support

Platooning will use a separate frequency channel since sharing channel with the verbose CAM and DENM broadcasting will force the platooning application to reduce its number of transmissions in certain situation. Many ITS-G5 equipped vehicles within radio range imply much CAM transmissions and probable DENM disseminations on channel 180 (a.k.a. control channel, CCH) and channel resources can quickly be consumed and DCC will kick in reducing the number of packet transmissions. To avoid disrupting the platooning application, as much as possible due to high CBR values, the platooning control messages (PCM) shall be transmitted on a separate channel (the most suitable one is channel 176, a.k.a., service channel 1, SCH1). This implies that platooning enabled vehicles are required to have dual-radio implementations, where one radio is tuned into channel 180 to be part of both CAM and DENM transmission/receptions and find other platooning enabled vehicles on the road. The second radio is tuned into suitable channel for platooning communication decided during the platoon establishment.

However, in ENSEMBLE, all communication will take place on channel 180 (CCH) and thus no physical channel switching will be performed. However, the protocol developed herein will contain the details and logic for changing frequency channel for the PCMs and the default channel will be set to 180.

REQ006: All ITS-G5 communication in ENSEMBLE will take place on channel 180 (CCH).

3.5. Packet encapsulation of platooning messages and CAMs

3.5.1. Introduction

Two types of messages are used in platooning – management and control – and these are detailed in Chapter 4. The platooning messages will be encapsulated in lower layers headers and trailers. This paragraph provides information about the encapsulation at the different layers. The encapsulation will look the same regardless if it is a management or control frame that is going to be transmitted and the CAMs will also use the same encapsulation.

In Figure 3, a highlevel picture of the packet encapsulation of the platooning PDU is found. For CAM it looks exactly the same but then it is the CAM PDU.

	PHY header	MAC header	LLC header	GN headers	BTP header	Platooning PDU	Security certificates	MAC trailer
Layers	Access			Network	Transport	Facilities	Network	Access

Figure 3: Packet encapsulation of the platooning PDU

3.5.2. BTP

BTP provides a connectionless transport of protocol data units (PDU). The platooning PDU will use the BTP-B header to pass its PDUs to the network layer and the GN protocol. The CAM is going to use the BTP-B header. BTP is outlined in ETSI EN 302 636-5-1 V1.2.1.

The BTP-A header carries both the source and the destination port (Figure 4). The destination port identifies the protocol entity at the ITS facilities layer in the destination of a BTP-PDU. The source port indicates the port that the ITS facilities layer protocol entity in the source has used to send the PDU. The source port represents the port to which a reply to the BTP PDU should be addressed in the absence of other information. The BTP-B header does not contain source port information since replies are not expected. Instead of source port information, there is a destination port field, which is set to 0 for CAM. There is a set of *well-known* BTP ports defined in ETSI TS 103 248 V1.2.1. BTP port 2001 shall be used for extended CAMs. Platooning needs to have two BTP ports: management, and control.

NOTE: A revision of ETSI TS 103 248 V1.2.1 needs to be performed to receive port numbers for platooning. This is done by invoking a revision of TS 103 248 through initiating a new work item and then allocation of port numbers are performed. This standard is often opened to accommodate new port numbers.

Field #	Field name	Octet position		Type	Unit	Description
		First	Last			
1	*Destination port*	0	1	16 bit integer		Identifies the protocol entity at the destination's ITS facilities layer.
2	*Source port*	2	3	16 bit integer		Identifies the port of the protocol entity at the source's ITS facilities layer.

Figure 4: BTP-A header

REQ007: CAMs shall use the BTP-B header

REQ008: CAMs shall set the field destination port to 2001.

REQ009: CAMs shall set the field destination port info to 0.

REQ010: Platooning PDUs shall use the BTP-B header.

REQ011: Platooning management PDU shall set the field destination port TBD and destination port info to 0.

REQ012: Platooning control PDU shall set the field destination port TBD and destination port info to 0.

3.5.3. GeoNetworking

The ENSEMBLE platooning protocol messages will be encapsulated, together with the BTP header, into a GN PDU and it will use the secured packet header as outlined in ETSI TS 103 097 V1.3.1 [14]. This imposes that the *GN Secure Packet format* as defined in Clause 9 of ETSI EN 302 636-4-1 shall be used. During development or for testing purposes security might be disabled. In that case, the *GN Header* as defined in Clause 9.3 of ETSI EN 302 636-4-1 can be used. Figure 5 shows the secured GN header.

The ENSEMBLE platooning protocol will use the single-hop broadcast GN messages to distribute CAMs, platoon control as well as platoon management messages such as join/leave request/response. Although GN unicast messages could have been selected for management messages, the GN unicast message header imposes unnecessary overhead and complexity. All the management messages defined in the ENSEMBLE platooning protocol already include destination and source identifiers that allows the delivery of a message to its final destination.

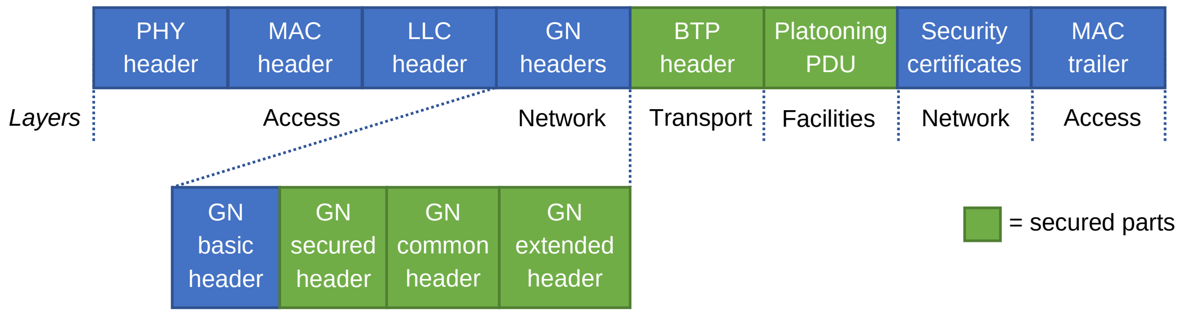

Figure 5: Secured GN encapsulation of the platooning PDU and BTP header

The single-hop broadcast GN header structure is found in Clause 9.8.4 of ETSI EN 302 636-4-1 V1.3.1. In Table 2, the parameter setting of the different fields throughout the three headers belonging to GN constituting the single-hop broadcast message is detailed.

Table 2: Parameter setting of the GN protocol for single-hop broadcast transmissions

Header	Field	Bits	Description	Extended CAMs	Platoon control message	Platoon management message
BASIC	Version	4	Identifies the version of the GN protocol	1	1	1
	NH	4	Next Header. Type of header immediately following the GeoNetworking	2 (Secured Header)	2 (Secured Header)	2 (Secured Header)
	Reserved	8	Set to 0	0	0	0
	LT	8	Life time	1000 ms (as per normal CAMs)	50 ms	1000 ms
	RHL	8	Remaining Hop Limit. Max number of hops. Drop if RHL is zero	1	1	1
COMMON	NH	4	Next Header. Type of header immediately following the GeoNetworking common header	2 (BTP-B)	2 (BTP-B)	2 (BTP-B)
	Reserved	4	Set 0	0	0	0
	HT	4	Header Type. Identifies the type of the GeoNetworking Header	0 (TSB)	0 (TSB)	0 (TSB)
	HST	4	Header Sub-Type. Identifies the type of the GeoNetworking Sub-Header	5 (SHB)	5 (SHB)	5 (SHB)
	TC	8	Traffic class that represents facilities layer requirements on packet transport.	SCF=0, CO=0, TCID=AC_BE	SCF=0, CO=0, TCID=AC_VO	SCF=0, CO=0, TCID=AC_BK
	Flags	8	Bit 0: Indicates whether the ITS-S is mobile or stationary (GN protocol constant itsGnIsMobile), Bit 1 to bit 7 set to 0.	1 (mobile)	1 (mobile)	1 (mobile)

	PL	16	PayLoad. Length of the GeoNetworking payload in bytes	Depends on packet size	Depends on packet size	Depends on packet size
	MHL	8	Maximum Hop Limit	1	1	1
	Reserved	8	Set to 0	0	0	0
EXTENDED	SO PV	192	Source Position Vector and it is of the type Long Position Vector containing the reference position of the source. 24 bytes	Current EGO position	Current EGO position	Current EGO position
	Media dependent data	32	4 bytes used by the media-dependent functionality if supported (see TS 102 636-4-2). Not used in ENSEMBLE. Set to 0.	0	0	0

REQ013: The single-hop broadcast packet header as outlined in Clause 9.8.4 of ETSI EN 302 636-4-1 V1.3.1 shall be used.

REQ014: The parameter setting of the single-hop broadcast packet with its different headers shall be as outlined in Table 2.

3.5.4. LLC and SNAP headers

The Logical Link Control (LLC) header outlined in IEEE 802.2 together with the extension Subnetwork Access Protocol (SNAP) header outlined in IEEE 802-2001 provides the possibility to distinguish between different network layer protocols through the unique Ethernet Types. GeoNetworking has the EtherType 8947 (hex). See Figure 6 for an outline of LLC and SNAP.

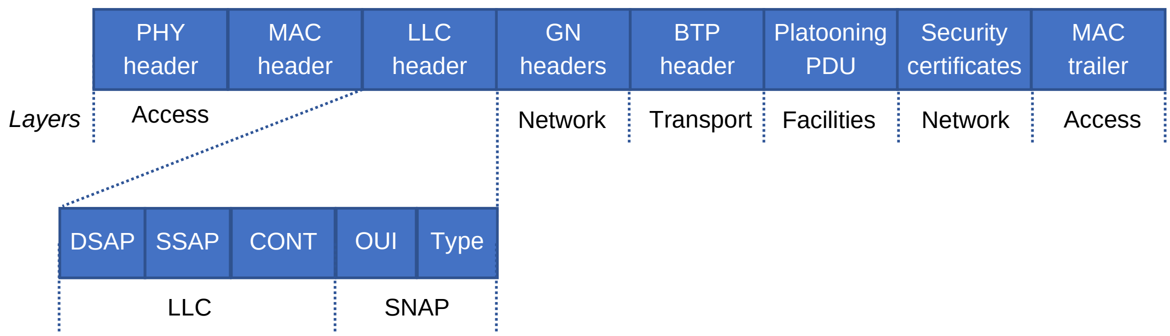

Figure 6: LLC encapsulation of the platooning PDU

Table 3: Parameter setting of the LLC and SNAP fields

	Field	Bits	Description	Value (hexadecimal)
LLC	DSAP	8	Destination Service Access Point. Set to default value of AA (hex) to inform that the SNAP header is included.	0xAA
	SSAP	8	Source Service Access Point. Set to default value of AA (hex) to inform that the SNAP header is included.	0xAA
	CONTROL	8	LLC offers three different services to the protocols above: (*i*) unacknowledged connectionless, (*ii*) connection mode, (*iii*) acknowledged connectionless. The unacknowledged connectionless service is used in LLC.	0x03
SNAP	OUI	24	IEEE organizationally unique identifier (OUI) is set to 0 if Ethernet Type (EtherType) is used for distinguishing between diffeent network protocols.	0x000000
	Type	16	The EtherType is a unique identifier for the network protocol on top of LLC. GeoNetworking's EtherType is 8947 (hex).	0x8947

REQ015: The LLC and SNAP headers as outlined in Table 3 shall be used.

3.5.5. IEEE 802.11p MAC & PHY

The medium access control sublayer and the physical layers of IEEE 802.11p is contained in the radio chipset. The MAC layer exposes four different priority queues to higher layers to prioritize between internal applications. These queues are called: AC_BK (access category background), AC_BE (AC best effort), AC_VI (AC video), and AC_VO (AC voice). Informative Annex B in ETSI EN 302 663 V1.2.1 contains a thorough explanation about the MAC procedure and the queues for the interested reader.

The PHY layer of IEEE 802.11p offers 8 different transfer rate where three are mandatory to support. The different rates are achieved by altering the modulation scheme together with the coding. The transfer rates are: **3**, 4.5, **6**, 9, **12**, 18, 24, and 27 Mbps (the bold ones are mandatory). The default rate for transmitting packets have been set to 6 Mbps. All CAM and DENM transmissions will use 6 Mbps. It is possible to change the transfer rate on a packet-per-packet basis.

The MAC address is changed every time the station ID in CAM is changed. The procedure of changing MAC address needs to be detailed here.

REQ016: The default rate for all messages transmitted in ENSEMBLE is 6 Mbps.

REQ017: The platoon control message shall use access category AC_VO.

REQ018: The platoon management message shall use access category AC_BK.

REQ019: The CAM shall use access category AC_BE.

REQ020: The MAC address shall change every time the station ID in the CAM is changed.

3.6. CAM

CAMs are used for announcing that a vehicle has platooning capability in ENSEMBLE. The trucks will transmit CAMs according to the generation rules outlined in EN 302 636-2. CAMs are always transmitted on channel 180 (CCH). One new container is introduced in the CAM in support of platooning, which holds one flag called `isJoinable`. When this flag is set to true, the vehicle is interested in receiving a JOIN REQUEST from a vehicle from behind. In Figure 7, the placement of the new Platooning container in the CAM structure is depicted. The platooning container does not break backward compatibility and vehicles not supporting the platooing container will disregard it.

```
CamParameters ::= SEQUENCE {
    basicContainer BasicContainer,
    highFrequencyContainer HighFrequencyContainer,
    lowFrequencyContainer LowFrequencyContainer OPTIONAL,
    specialVehicleContainer SpecialVehicleContainer OPTIONAL,
    ...,
    platooningContainer    PlatooningContainer OPTIONAL,
    ...
}
```

Figure 7: The placement of the platooning container in the CAM

REQ021: The platooningContainer shall always be included in the CAM.

The details of the platooning container are found in Figure 8. It contains one flag called `isJoinable`, which will be used for signalling if a vehicle accept other vehicles to platoon with or not. The platooning container contains “three dots” implying that it can be expandable to contain more parameters that might be identified as necessary.

```
PlatooningContainer ::= SEQUENCE {
        isJoinable BOOLEAN,
        ...
}
```

Figure 8: The platooning container contains one flag called `isJoinable`

REQ022: The PlatooningContainer shall include one BOOLEAN flag.

3.7. Application ID

Each ITS application is globally identified by an ITS-AID and these are outlined in ETSI TS 102 965 V1.4.1 [11]. ISO 17419 regulates allocation of new ITS-AID globally. When starting the ENSEMBLE project no ITS-AID number has been defined for platooning. To request the assignment of a new ITS-AID during the project we shall use the template available at [12]. Until a new Application ID is assigned for platooning, a testing/private ITS-AID shall be used.

ITS-AID is also referred as PSID at IEEE 1609.2 [13]. PSID are used to indicate the permissions that a certificate holder has to sign application data with a given certificate. This point will be considered when issuing/requesting new certificates from the PKI (Private Key Infrastructure).

REQ023: The CAM shall use ITS-AID 0x24.

REQ024: The platooning application shall use ITS-AID 0xXY (TBD).

3.8. Security

The platooning protocol will use the already existing PKI developed for day-one services in Europe by signing and verifying messages. In addition, also encryption of platoon data is enabled by the exchange of symmetric keys during the establishment of the platoon. The security approach outlined in this deliverable might change depending on the outcome of ENSEMBLE deliverable D2.9 treating security.

REQ025: Clause 4.8.1 outlining the security profiles shall be implemented.

3.8.1. Security profiles

This subchapter is an extension to ETSI TS 103 097 V1.3.1 [14] Clause 7.1. The suggested extensions will also result in a request to update ETSI TS 102 965 V1.3.1 [11], since platooning will use one additional ITS-AID.

Vehicles that has the platooning ITS-AID should include a public encryption key in its authorization tickets.

Security profiles themselves are new.

Join Request

The secure data structure containing Join Platoon Request Message shall be of type `EtsiTs103097Data-Signed` as defined in ETSI TS 103 097 V1.3.1 [14] Clause 5.1 and [14] Annex A, containing the Join Platoon Request Message as the `ToBeSignedDataContent`, with the additional constraints defined in [14] Clause 5.2 and thisfollowing:

- The component signer of `SignedData` shall be constrained as follows:
  - `SignerIdentifier` shall be of choice digest
- The component `tbsdata.headerInfo` of `SignedData` shall be further constrained as follows:
  - psid: this component shall encode the ITS-AID value for platooning. Platooning does not have an ITS-AID yet but it needs to be allocated and an update of [11] needs to be done.
- All other components of the component `tbsdata.headerInfo` allowed to be present according to [14] Clause 5 shall not be used and be absent.

Join Response

The secure data structure containing Join Platoon Response Message shall be of type `EtsiTs103097Data-SignedAndEncrypted` as defined in [14] Clause 5.1 and [14] Annex A, containing the Join Platoon Response Message as the `ToBeSignedAndEncryptedDataContent`, with the additional constraints defined in [14] Clause 5.2 and thisfollowing:

- The component recipients of `EncryptedData` shall be of type `SequenceOfRecipientInfo` and further constrained as follows:
  - The `SequenceOfRecipientInfo` shall only contain one entry, that entry shall be of choice `signedDataRecipInfo`
- The component signer of `SignedData` shall be constrained as follows:
  - `SignerIdentifier` shall be of choice digest
- The component `tbsdata.headerInfo` of `SignedData` shall be further constrained as follows:
  - psid: this component shall encode the ITS-AID value for platooning. Platooning does not have an ITS-AID yet but it needs to be allocated and an update of [11] needs to be done.
- All other components of the component `tbsdata.headerInfo` allowed to be present according to [1] Clause 5 shall not be used and be absent.

Leave Platoon

The secure data structure containing Leave Platoon Message shall be of type `EtsiTs103097Data-Signed` as defined in [14] Clause 5.1 and [14] Annex A, containing the Leave Platoon Request Message as the `ToBeSignedDataContent`, with the additional constraints defined in [14] Clause 5.2 and thisfollowing:

- The component signer of `SignedData` shall be constrained as follows:

    - `SignerIdentifier` shall be of choice certificate
- The component `tbsdata.headerInfo` of `SignedData` shall be further constrained as follows:
    - psid: this component shall encode the ITS-AID value for platooning. Platooning does not have an ITS-AID yet but it needs to be allocated and an update of [11] needs to be done.
- All other components of the component `tbsdata.headerInfo` allowed to be present according to [14] Clause 5 shall not be used and be absent.

Platoon Control

The secure data structure containing Platoon Data Message shall be of type `EtsiTs103097Data-SignedAndEncrypted` as defined in [14] clause 5.1 and [14] Annex A, containing the Platoon Control Message as the `ToBeSignedAndEncryptedDataContent`, with the additional constraints defined in [14] Clause 5.2 and thisfollowing:

- The component recipients of `EncryptedData` shall be of type `SequenceOfRecipientInfo` and further constrained as follows:
    - The SequenceOfRecipientInfo shall only contain one entry, that entry shall be of choice `PreSharedKeyRecipientInfo`
    - The `PreSharedKeyRecipientInfo` shall contain the digest of the symmetric encryption key of the platoon
- The component signer of `SignedData` shall be constrained as follows:
    - As default, `SignerIdentifier` shall be of choice digest
        - If the ITS-S receives a Platoon Control Message signed by a previously unknown AT, it shall include the choice certificate immediately in its next Platoon Data Message, instead of including the choice digest.
        - If an ITS-S receives a Platoon Control Message that includes a `tbsdata.headerInfo` component of type `inlineP2pcdRequest`, then the ITSS shall evaluate the list of certificate digests included in that component: If the ITS-S finds a certificate digest of the currently used authorization ticket in that list, it shall include a the choice certificate immediately in its next Platoon Control Message, instead of including the choice digest.
        - If the AT of the ITS-S has changed, it shall include the choice certificate immediately in its next Platoon Control Message, instead of including the choice digest.
- The component `tbsdata.headerInfo` of `SignedData` shall be further constrained as follows:
    - psid: this component shall encode the ITS-AID value for platooning. Platooning does not have an ITS-AID yet but it needs to be allocated and an update of [11] needs to be done.
- The component `inlineP2pcdRequest` shall be included and shall contain the digests of certificates currently unknown to the ITS-Station if the ITS-S received a Platoon Data Message with the component signer of `SignedData` set to the choice digest, and this digest points to an unknown authorization ticket.
- All other components of the component `tbsdata.headerInfo` allowed to be present according to Clause 5 in [14] shall not be used and be absent.

4. PLATOONING PROTOCOL

4.1. Introduction

This chapter gives an overview of the platooning protocol's logic together with the different message types (control and management) and new data elements. To enable the functionality of platooning a set of preconditions must likely to be fulfilled, however, it is out of scope for this deliverable to define. In Table 4, examples of preconditions are outlined and the preconditions are divided into dynamic and static, where the latter can change on a daily basis down to on a minute basis whereas the static ones are changed on weekly up to monthly basis. In this deliverable the assumption is that all preconditions are fulfilled and the vehicle together with driver are eligible to be part of a platoon.

Table 4: Examples of preconditions that might need to be fulfilled before enabling platooning

Precondition		Description
Static	Inspection	The truck and trailer have been through its "annual" inspection.
	Subscription	There might be a subscription to a specific platooning service regulating access to the platooning system.
	Country	There might be country-specific regulation for platoons, such as how many vehicles that are allowed in a platoon in a specific country. It might take some time to harmonize legislation around platoon operation on real roads.
	Road infrastructure	There might be bridges and similar physical infrastructure influencing for example distance and/or speed of platoon.
	Geofencing	There might be special environmental zones to consider.
Dynamic	Location	The vehicle needs to be on a road network permitting platoons.
	Weather	Local weather conditions may prohibit platooning.
	Road conditions	Road conditions could differ from weather conditions. Bad road conditions will prohibit platooning. For example, a road can be icy even though the sun is shining in the winter.
	Day-one services	There might be accidents, traffic jams and road works, during the platoon travel that will inactivate the platooning capability (this depends of course on how advanced use cases the platoon can handle, probably mor advanced as time goes by).
	In-vehicle warnings	Before and during the course of the platoon no warnings in the dashboard shall appear or be present.
	Heavy/Long vehicle	The truck could exceed possible physical dimension due to carried load to be able to platoon.
	Other vehicle specific features	There might be other vehicle related features that needs to be set. For example, should the adaptive cruise control (ACC) be a precondition?

If all preconditions are fulfilled, and the driver/haulage company wants to platoon, the vehicle will signal this through the cooperative awareness message (CAM). In the CAM, a new container has been added carrying one flag stating if the vehicle is interested in receiving join requests or not.

In Figure 9, a high-level picture of two vehicles joining a platoon, transmit control messages and leave the platoon.

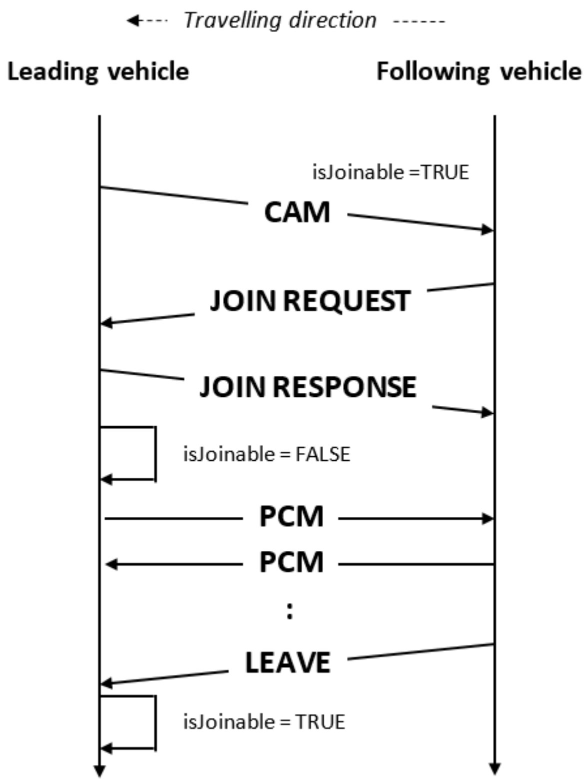

Figure 9: Overview of platooning from joining to leaving

The platoon will also communicate with smart road infrastructure using V2X communication and this needs to be further elaborated on during the course of the ENSEMBLE project. Smart road infrastructure uses the same lower layer standardized protocols as outlined in Chapter 3 to be interoperable with vehicles. The V2I communication can take place either by detailing a new control message outlined in the platooning protocol or using suitable already standardised infrastructure messages.

4.2. Protocol logic

The V2X protocol consists of four building blocks being (0) idle, (1) join, (2) platoon, and (3) leave, described in subsequent subchapters.

4.2.1. (0) IDLE

Introduction

CAM is used for announcing on the V2X communication channel (180, CCH) that a vehicle is eligible to be part of a platoon and if the vehicle is already part of a platoon, if a new vehicle can join. One boolean flag is introduced in the CAM through a new platoon container to signal that the vehicle is interested in platooning. The flag is called `isJoinable`. The introduction of a platoon container is not violating the backward compatibility to the legacy CAM standard. Only vehicles interested in reading this container will read it and the other vehicles will ignore it.

The flag `isJoinable` is always set to true as long as the selected list of preconditions are met, regardless if the vehicle is part of a platoon or not. However, the flag `isJoinable` changes status depending on if the vehicle is part of a platoon or not and also based on the position in the platoon. Table 5 describes the flag `isJoinable`.

Table 5: Describes the flag `isJoinable`

#	Flag	Status [T/F]	Description
1	`isJoinable`	T	A single vehicle or the last vehicle in a platoon. The vehicle assesses ”Join requests”.
2	`isJoinable`	F	A vehicle might be part of a platoon and the maximum number of trucks has been reached and then `isJoinable` is set to F. Or the vehicle cannot platoon due to that either dynamic or static preconditions are not fulfilled.

Preconditions

Single vehicle transmitting CAM with flag `isJoinable` set to true.

Description

In the (0) IDLE mode, the vehicle is transmitting CAMs on channel 180 (CCH) with `isJoinable` set to true. The vehicle move from (0) IDLE mode to (1) JOIN mode either by receiving/transmitting a JOIN REQUEST. Figure 10 outlines the steps in (0) IDLE mode.

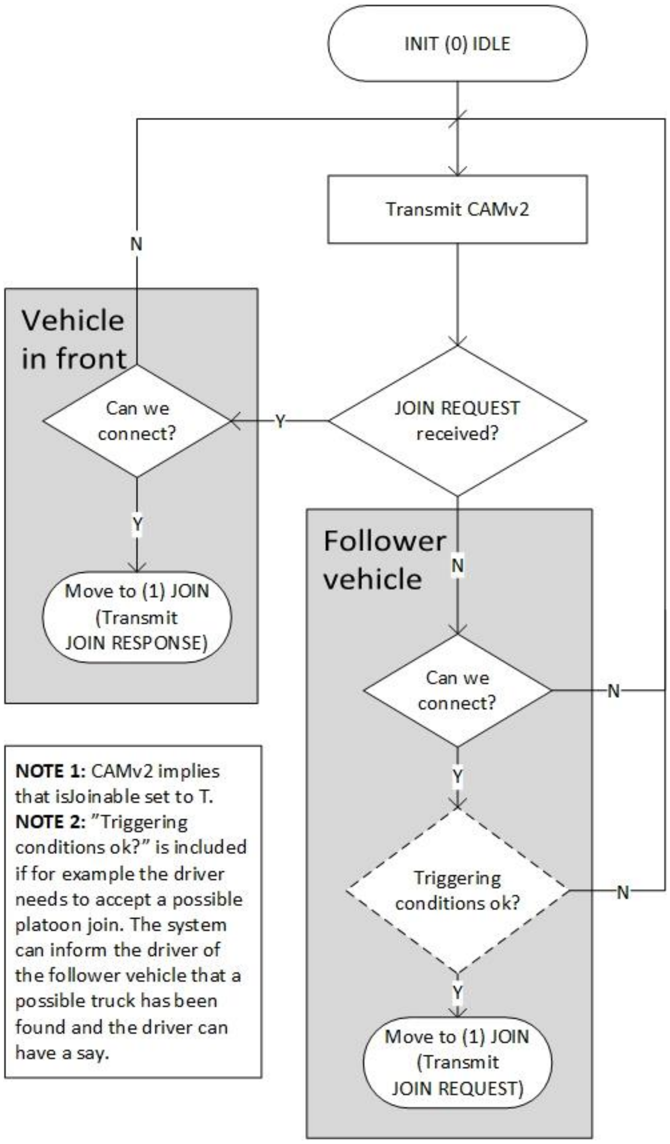

Figure 10: Outlines what happens in (0) IDLE

4.2.2. (1) JOIN

Introduction

JOIN procedure is initiated by a vehicle sending a JOIN REQUEST if it has a vehicle in front within a certain distance transmitting CAMs with `isJoinable` set to TRUE.

Preconditions

1) Received JOIN REQUEST
2) Transmitted JOIN REQUEST

Description

A single vehicle transmits up to 10 JOIN REQUEST before giving up to join a vehicle in front that is within a certain distance from the ego vehicle. The JOIN REQUEST message is transmitted with 10 Hz, i.e., 100 ms between JOIN REQUEST messages. Thus, the vehicle is trying for one second to join the vehicle/platoon in front. As soon as the vehicle receives a JOIN RESPONSE, it starts to transmit PLATOON CONTROL MESSAGE (PCM) and moves to PLATOON. The joining procedure can take up to one second and can be as fast as 30-50 ms.

Upon reception of JOIN REQUEST, the receiving vehicle (which is in front of the vehicle transmitting JOIN REQUEST) transmits 10 JOIN RESPONSE until the first PCM has been received by the joining vehicle. The JOIN RESPONSE is transmitted with 10 Hz, i.e., 100 ms between JOIN RESPONSE messages. The JOIN RESPONSE contains an encryption key for encryption of PCMs. The vehicle is also continuing or starting up to transmit PCMs depending on if the vehicle receiving a JOIN REQUEST is part of an existing platoon or if this is a new platoon. The receiving vehicle moves to PLATOON directly when first JOIN RESPONSE has been transmitted and starts to also transmit PCMs.

Figure 11 shows (1) JOIN.

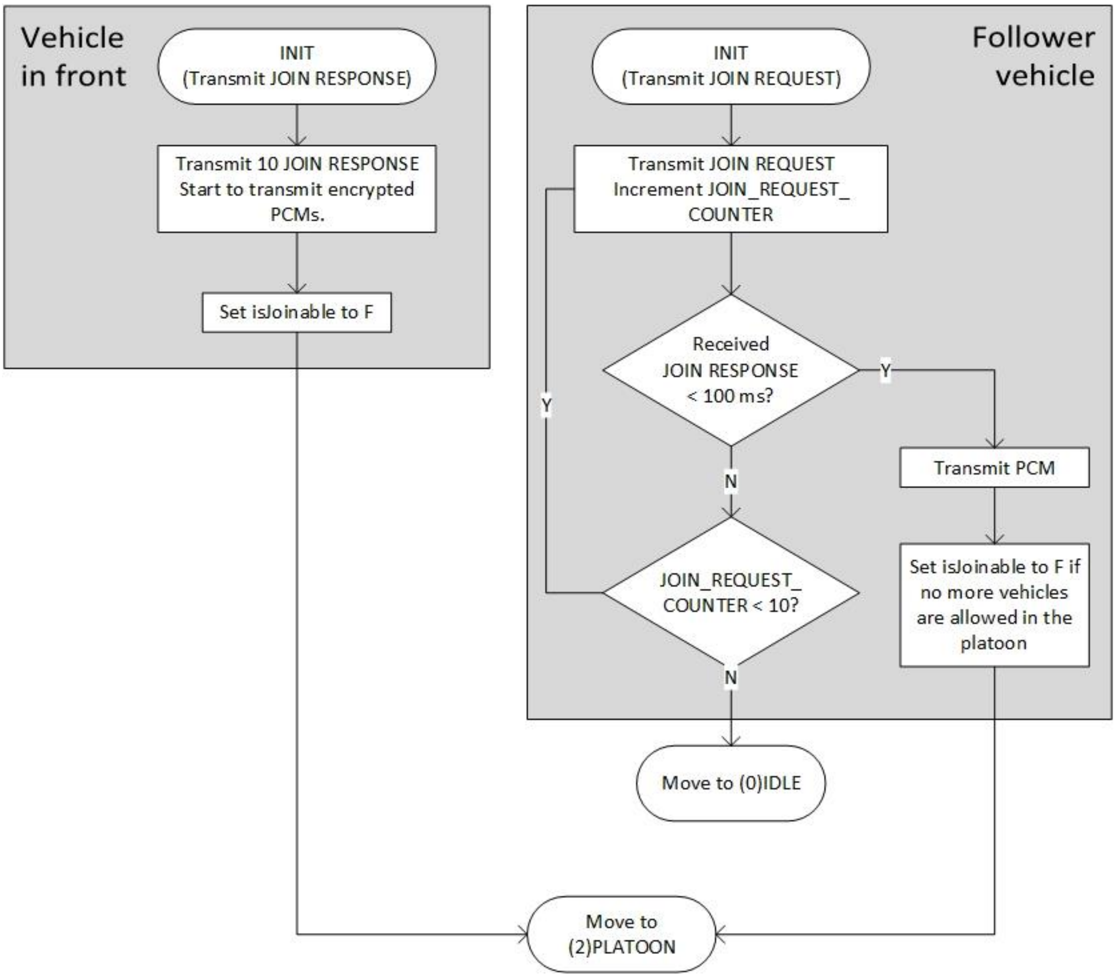

Figure 11: JOIN procedure

Exceptions

If the vehicle receiving a JOIN REQUEST is for a specific reason not interested in platooning with another specific vehicle then the vehicle does not send JOIN RESPONSE. The vehicle requested to join would in consequence run into a timeout.

4.2.3. (2) PLATOON

Introduction

In PLATOON mode, vehicles are transmitting and receiving PCMs.

Preconditions

1. Transmitting PCMs
2. Receiving PCMs

Description

In the (2) PLATOON mode, the vehicle transmits a new PCM every 50 ms until the vehicle is deciding upon to leave the platoon then the platoon member is creating a LEAVE message. If another vehicle is deciding to leave the platoon also this will cause the ego vehicle to move to LEAVE. When PCMs have been absent from any of the vehicles participating in the platoon for a certain period of time, the platoon needs to be dissolved and re-initiated again.

In Figure 12, an overview of the reception part of the platoon is depicted.

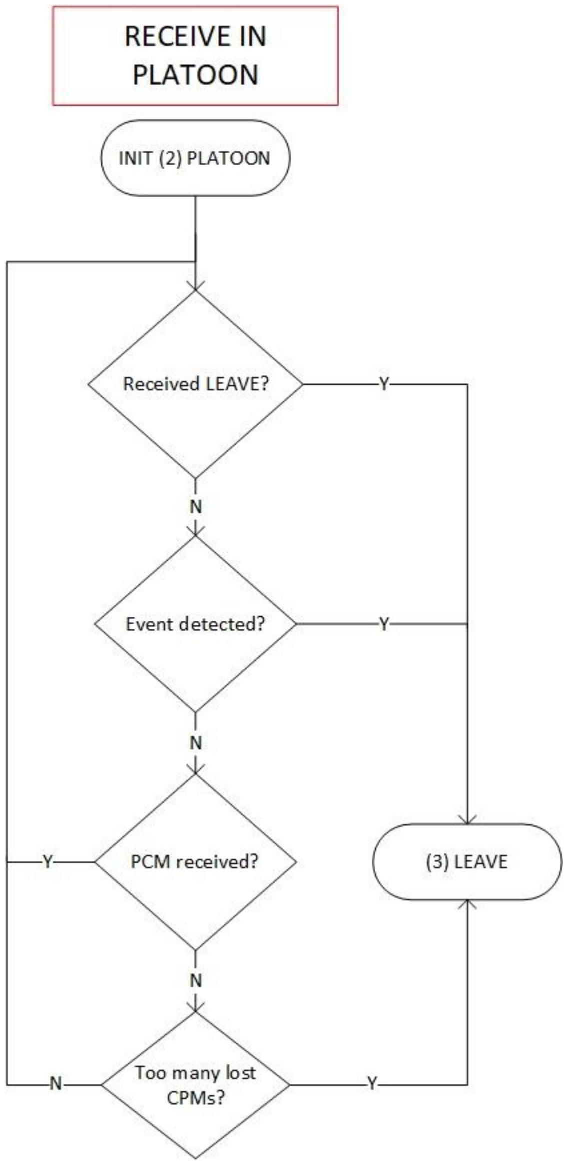

Figure 12: Receiving part

The transmitting part of the platoon is found in Figure 13. When a vehicle wants to leave a platoon it is signalling already in the last PCMs that it has an intention to leave.

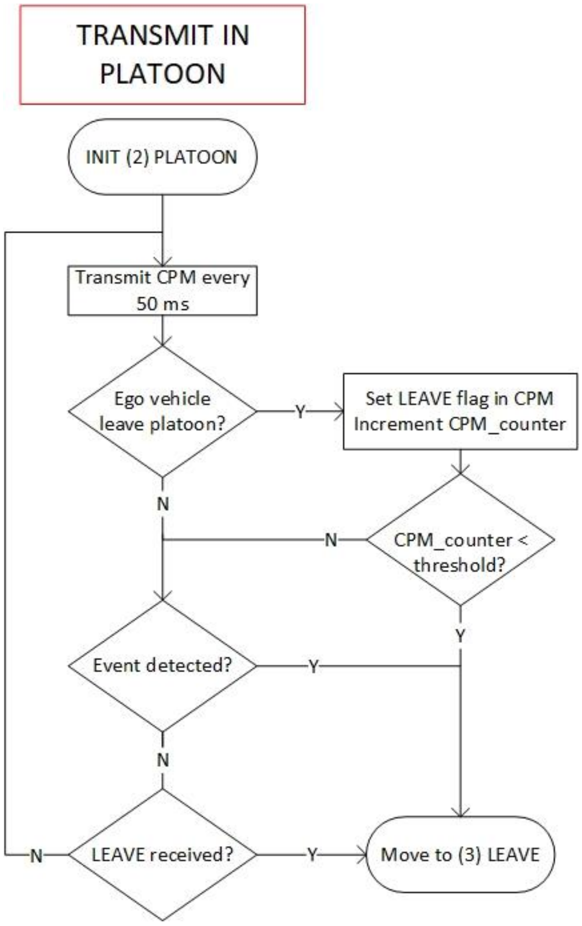

Figure 13: Transmitting part

Exceptions

Events during the platooning, e.g. emergency brake.

4.2.4. (3) LEAVE

Introduction

Vehicles end up in LEAVE when either PCMs have not been received by any other vehicle(s) during a period of time, or because one vehicle would like to leave a platoon.

Preconditions

An event has happened during (1) JOIN or (2) PLATOON. Ego vehicle is going to do a LEAVE maneuver. A LEAVE message has been received from another vehicle.

Description

LEAVE is a short-termed state, where the vehicle only transmits 10 LEAVE messages with a cause code describing the leave. In Figure 14, LEAVE is outlined.

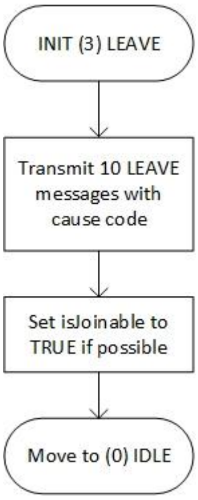

Figure 14: Leave procedure

Exceptions

Events during the platooning, e.g., emergency brake.

4.3. Message sets

Draft ASN.1 files for the management frames (join request, join response, leave) and control frame (containing the signals for operation of the platoon) are provided in Appendix A. Details on the addition of a platooning container in the CAM without breaking backward compatibilty are also found there.

4.3.1. Management frames

Three management frames have been defined to enable joining and leaving the platoon and those are described in Table 6.

Table 6: Description of management frames

Management frame name	Description
JOIN REQUEST	This message is sent by a vehicle who wants to join a vehicle. The joining procedure is always assuming that a vehicle behind another vehicle initiates joining by sending the JOIN REQUEST.

JOIN RESPONSE	JOIN RESPONSE is sent by the vehicle receiving the JOIN REQUEST
LEAVE	This message is transmitted when the actual leave is taking place. The intention to leave will be announced in the control frame (PCM) some time before the physical leave.

4.3.2. Control frame

The control frame called platoon control message (PCM) can be perceived as the heartbeat of the platooning application. Those are transmitted with 20 Hz after a successful join procedure. No acknowledgements (ACK) are used but instead implicit ACKs are used, implying that a vehicle in the platoon can expect a new message from all platoon member around every 50 ms period. If several consecutive packets are missing from a vehicle, the ego vehicle has to adapt its behaviour to a new situation. The PCM contains all necessary data for controlling the vehicle both longitudinally as well as laterally to enable safe platooning.

The PCMs should be encrypted using a symmetric encryption key. The leading truck in the platoon creates the symmetric key when a platoon is formed. When another vehicle is joining an existing platoon, the vehicle in front of the joining vehicle will hand over the key to the joining vehicle within a join response. The symmetric key is a pre-shared key as defined in IEEE 1609.2 [13]. The recipient ID of the symmetric encryption key is generated by taking the digest of the SHA256 hashed OER Encoded SymmetricEncryptionKey structure. And the recipient ID for all vehicles that have generated the recipient ID will consequently have the same result, same ID. So it is possible to address all trucks in the platoon on security layer at once.

4.4. Data dictionary

ETSI TS 102 894-2 [15] outlines data elements (DE) and data frames (DF) for constructing messages. The platooning protocol uses existing DE and DF from TS 102 894-2, which are outlined in Table 7. For details around these have a look in TS 102 894-2. In subsequent subchapters new data elements introduced by the platooning protocol are described. They are in the same format as in TS 102 894-2. It should be noted that the defined DE/DF by the platooning protocol are still subject to changes.

Table 7: Data types used by the platooning protocol already present in TS 102 894-2

Data element	Short description
StationID	Identifier for an ITS Station
StationType	The type of an ITS Station
ReferencePosition	The geographical point position
Heading	A heading in the WGS84 coordinate system
VehicleLength	Length of a vehicle
SequenceNumber	Sequence number

CauseCode	Encoded value of a traffic event type
Speed	Speed and corresponding accuracy
YawRate	Yaw rate of a vehicle at a point in time
Curvature	Curvature of the vehicle trajectory

4.4.1. DE_GrossCombinationVehicleWeight

Descriptive Name	GrossCombinationVehicleWeight
Identifier	DataType_n
ASN.1 representation	`GrossCombinationVehicleWeight ::= INTEGER {tenKg(1), outOfRange(32766), unavailable(32767)} (0..32767)`
Definition	The weight of the entire vehicle combination, including trailers. 32767 if not available
Unit	10 kg
Category	Vehicle information

4.4.2. DE_PlatoonPosition

Descriptive Name	PlatoonPosition
Identifier	DataType_n
ASN.1 representation	`PlatoonPosition ::= INTEGER {leader(1), firstFollower(2), unavailable(32)} (1..32)`
Definition	A vehicles position in a platoon: -1 for the leader -2 for the first follower -32 if not available
Unit	N/A
Category	Platooning

4.4.3. DE_VINNumber

Descriptive Name	VINNumber
Identifier	DataType_n
ASN.1 representation	`VINNumber ::= IA5String (SIZE (11..20))`
Definition	The VIN-number of the vehicle. Typically 17 characters. The following characters are used: 0-9 and A-Z, except for O and Q.
Unit	N/A
Category	Platooning, vehicle information

4.4.4. DE_PowerToMassRatio

Descriptive Name	PowerToMassRatio
Identifier	DataType_n
ASN.1 representation	`PowerToMassRatio ::= INTEGER { oneWperKg(1), outOfRange(255), unavailable(256)} (1 .. 256)`
Definition	Power to mass ration of the vehicle combination is defined as the engine power in W divided by the gross combination vehicle weight in kg.
Unit	W/kg
Category	Platooning, vehicle information

4.4.5. DE_RoadInclination

Descriptive Name	RoadInclination
Identifier	DataType_n
ASN.1 representation	`RoadInclination ::= INTEGER {pointOnePercentUp(1), pointOnePercentDown(-1), unavailable(32)} (-31 .. 32)`
Definition	The road inclination in %, 32 if not available
Unit	N/A
Category	Vehicle information, road topology information

4.4.6. DE_DistanceToTargetAhead

Descriptive Name	DistanceToTargetAhead
Identifier	DataType_n
ASN.1 representation	`DistanceToTargetAhead ::= INTEGER {oneCm(1), unavailable(16383)} (0..16383)`
Definition	Distance to radar target ahead, 16383 if not available
Unit	0.01 m
Category	Vehicle information

4.4.7. DE_LaneMarkingDistance

Descriptive Name	LaneMarkingDistance
Identifier	DataType_n
ASN.1 representation	`LaneMarkingDistance ::= INTEGER {oneCm(1), unavailable(511)} (0..511)`
Definition	Distance to lane marking measured from the middle of the vehicle. 511 if not available
Unit	0.01 m
Category	Vehicle information

4.4.8. DF_LongitudinalHdAcceleration

Descriptive Name	LongitudinalHdAcceleration
Identifier	DataType_n
ASN.1 representation	`LongitudinalHdAcceleration ::= SEQUENCE { longitudinalAccelerationValue LongitudinalHdAccelerationValue, longitudinalAccelerationConfidence HdAccelerationConfidence }`
Definition	It indicates the vehicle acceleration at longitudinal direction and the accuracy of the longitudinal acceleration, in a higher definition than the DF_LongitudinalAcceleration. The DF shall include: •longitudinalAccelerationValue: longitudinal acceleration value at a point in time. It shall be presented as the *LongitudinalAccelerationValue* •longitudinalAccelerationConfidence: accuracy of the reported longitudinal acceleration value with a predefined confidence level. It shall be presented as the *AccelerationConfidence*.
Unit	N/A
Category	Vehicle information, platooning

4.4.9. DE_LongitudinalHdAccelerationValue

Descriptive Name	LongitudinalHdAccelerationValue
Identifier	DataType_n
ASN.1 representation	`LongitudinalHdAccelerationValue ::= INTEGER { pointZeroOneMeterPerSecSquaredForward(1), pointZeroOneMeterPerSecSquaredBackward(-1), unavailable(1610)} (-1600 .. 1610)`
Definition	High definition vehicle acceleration at longitudinal direction in the centre of the mass of the empty vehicle. It corresponds to the vehicle coordinate system as specified in ISO 8855. The values follows the same logic as the LongitudinalAccelerationValue DE, but with a 10 times larger value set, due to the higher definition. Negative values indicate that the vehicle is braking. For retardation equal to or greater than 16 m/s^2, the value shall be set to -1600. Positive values indicate that the vehicle is accelerating. For acceleration equal to or greater than 16,09 m/s^2 the value shall be set to 1609. When the data is unavailable, the value shall be set to 1610. The DE is used in LongitudinalHdAcceleration DF.
Unit	0,01 m/s^2
Category	Vehicle information, platooning

4.4.10. DE_HdAccelerationConfidence

Descriptive Name	HdAccelerationConfidence
Identifier	DataType_n
ASN.1 representation	`HdAccelerationConfidence ::= INTEGER { pointZeroOneMeterPerSecSquared(1), outOfRange(1022), unavailable(1023)} (0 .. 1023)`
Definition	The absolute accuracy of a reported vehicle acceleration value with a predefined confidence level (e.g. 95 %). The required confidence level is defined by the corresponding standards applying the DE. The value shall be set to: • 1 if the acceleration accuracy is equal to or less than 0,01 m/s^2. • n (n > 1 and n < 1021) if the acceleration accuracy is equal to or less than n × 0,01 m/s^2. • 1022 if the acceleration accuracy is out of range i.e. greater than 10,21 m/s^2. • 1023 if the data is unavailable. The DE is used in LongitudinalHdAcceleration DF. NOTE: The fact that an acceleration value is received with confidence set to 'unavailable(1023)' can be caused by several reasons, such as: −The sensor cannot deliver the accuracy at the defined confidence level because it is a low-end sensor, -The sensor cannot calculate the accuracy due to lack of variables, or -There has been a vehicle bus (e.g. CAN bus) error. In all 3 cases above, the reported acceleration value may be valid and used by the application. If an acceleration value is received and its confidence is set to 'outOfRange(1023)', it means that the value is not valid and therefore cannot be trusted. Such value is not useful for the application.
Unit	0,01m/s^2
Category	Vehicle information

4.4.11. DE_PlatooningLevel

Descriptive Name	PlatooningLevel
Identifier	DataType_n
ASN.1 representation	`TBD`
Definition	TBD
Unit	N/A
Category	Platooning

4.4.12. DE_SymmetricKeyType

Descriptive Name	SymmetricKeyType
Identifier	DataType_n
ASN.1 representation	`SymmetricKeyType ::= ENUMERATED {aes128ccm(0), ...}`
Definition	The type of the symmetric key, used to encrypt platooning control messages. Today only AES 128 CCM is supported.
Unit	N/A
Category	Platooning

4.4.13. DE_ReasonToLeave

Descriptive Name	ReasonToLeave
Identifier	DataType_n
ASN.1 representation	`ReasonToLeave ::= ENUMERATED {unavailable(0), divert(1), weather(2), roadCondition(3), roadWork(4), accident(5), invalidCertificate(6), merge(7), split(8), ...}`
Definition	Reason for leaving a platoon: -unavailable(0): Reason not known, or not available -divert(1) -weather(2): Weather not good enough for driving in a platoon -roadCondition(3): Bad road condition (slippery road), or road not suitable for platooning. -roadWork(4): Road work -accident(5): Traffic accident -invalidCertificate(6): Another vehicle in the platoon has a certificate which is not in my trust list -merge(7): Used when the two platoon are merged, in order to leave the existing platoon for the merged platoon. -split(8): Used when driving in a platoon and there is a new vehicle, typically an intruder, detected in front and the ego-vehicle thus can no longer be member of that platoon.
Unit	N/A
Category	Platooning

4.4.14. DE_FrequencyChannel

Descriptive Name	FrequencyChannel
Identifier	DataType_n
ASN.1 representation	`FrequencyChannel ::= INTEGER (1..7)`
Definition	Enumerates the frequency channels. Used in the response to a join platoon message, to notify the joining vehicle about which frequency channel is used to receive the vehicle control messages on.
Unit	N/A
Category	Platooning

4.4.15. DE_SymmetricKeyData

Descriptive Name	SymmetricKeyData
Identifier	DataType_n
ASN.1 representation	`SymmetricKeyData ::= OCTET STRING (SIZE(256..512))`
Definition	A symmetric encryption key, used to encrypt/decrypt platoon
Unit	N/A
Category	Platooning

4.4.16. DE_PlatoonID

Descriptive Name	PlatoonID
Identifier	DataType_n
ASN.1 representation	`PlatoonID ::=   INTEGER(0..4294967295)`
Definition	The id of a platoon
Unit	N/A
Category	Platooning

4.4.17. DE_GenerationDeltaTime

Descriptive Name	GenerationDeltaTime
Identifier	DataType_n
ASN.1 representation	`INTEGER {oneMilliSec(1)} (0..65535)`
Definition	Time corresponding to the time when the platoon control message was generated. The value of the DE shall be wrapped to 65 536. This value shall be set as the remainder of the corresponding value of TimestampIts divided by 65 536 as below: generationDeltaTime = TimestampIts mod 65 536 TimestampIts represents an integer value in milliseconds since 2004-01-01T00:00:00:000Z as defined in ETSI TS 102 894-2 [15].
Unit	N/A
Category	Platooning

5. CONCLUSION

The present deliverable specifies a facilities layer protocol supporting the platooning application by introducing management and control frames. It makes use of already standardized protocols such as ITS-G5, GeoNetworking and BTP. Further, the security framework developed for C-ITS day-one applications based on PKI is used to create a trust domain with the addition of encrypting platooning data. The developed protocol resides together with other protocols such as CAM in the facilities. Vehicles find each other by signalling in CAMs that they are available for platooning. Once a platoonable vehicle detects another plantoonable vehicle in front of it, the follower vehicle will initiate a join procedure to establish a platoon or join an already existing platoon. When a vehicle wants to leave the platoon, it signals this in a number of control frames (PCMs) and when the actual leave takes place it transmits specific leave messages.

The deliverable also elaborates on a first version of ASN.1 descriptions of the different message types and included signals, which are found in Appendix A. However, these are still subject to changes as well as the new data elements found in Chapter 4 of present deliverable. Further, the final security for platooning will be treated in a separate deliverable called D2.9.

6. REFERENCES

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APPENDIX A – DRAFT ASN.1 FILES OF PLATOON MESSAGES

A.1 Introduction

The ASN.1 files provided in this appendix are still subject to changes. These will be updated in the course of the project.

A.2 Management frames – join request, join response and leave request

```
PMM-PDU-Descriptions {
 itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) en (302637) pmm
(13) version (1)
}

DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS
       ItsPduHeader, StationID, StationType, ReferencePosition, VehicleLength, Heading
FROM ITS-Container {
              itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts
(102894) cdd (2) version (1)
       }
       LongitudinalHdAccelerationValue, PowerToMassRatio, VehicleID, PlatoonPosition
FROM Platoon-Container
       GenerationDeltaTime FROM CAM-PDU-Descriptions;

PMM ::= SEQUENCE {
       header ItsPduHeader,
       stationType StationType,
       referencePosition ReferencePosition,
       heading Heading,
       generationDeltaTime GenerationDeltaTime,
       message CHOICE {
             joinRequest JoinRequest,
             joinResponse JoinResponse,
             leaveRequest LeaveRequest
       }
}

JoinRequest ::= SEQUENCE {
       receiver StationID,
       brakeCapacity LongitudinalHdAccelerationValue,
       powerToMassRatio PowerToMassRatio,
```

```
        platooningLevel PlatooningLevel,
        vehicleLength VehicleLength,
        ...
}

JoinResponse ::= SEQUENCE {
        respondingTo StationID,
        joinResponseStatus CHOICE {
             notAllowedToJoin NULL,
             allowedToJoin JoinResponseInfo
        }

}

JoinResponseInfo ::= SEQUENCE {
        symmetricKey SymmetricKey,
        frequencyChannel FrequencyChannel,
        platoonId PlatoonID,
        maxNrOfVehiclesInPlatoon INTEGER(2..31),
        joiningAtPosition PlatoonPosition
}

LeaveRequest ::= SEQUENCE {
        vehicleId VehicleID,
        platoonPosition PlatoonPosition,
        reason ReasonToLeave
}


SymmetricKey ::= SEQUENCE {
        keyType SymmetricKeyType,
        key SymmetricKeyData
}

PlatooningLevel ::= ENUMERATED {longitudinalOnly(0), lateralAndLongitudinal(1), ...}

SymmetricKeyType ::= ENUMERATED {aes128ccm(0), ...}

ReasonToLeave ::= ENUMERATED {unavailable(0), divert(1), weather(2), roadCondition(3),
roadWork(4), accident(5), invalidCertificate(6), merge(7), split(8), ...}

FrequencyChannel ::= INTEGER (1..7)

SymmetricKeyData ::= OCTET STRING (SIZE(32..64))

PlatoonID ::= OCTET STRING (SIZE(16))

END
```

A.3 Control frame

```
PCM-PDU-Descriptions {
 itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) en
(302637) pcm (14) version (1)
}

DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS
      ItsPduHeader, StationID, StationType, SequenceNumber, ReferencePosition,
VehicleLength, VehicleLengthValue,
      LateralAcceleration, YawRate, Curvature, Speed, SpeedValue, CauseCode,
Heading FROM ITS-Container {
            itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1
(1) ts (102894) cdd (2) version (1)
      }
      PowerToMassRatio, LongitudinalHdAcceleration,
LongitudinalHdAccelerationValue, VehicleID, PlatoonPosition FROM Platoon-
Container
      GenerationDeltaTime FROM CAM-PDU-Descriptions;

PCM ::= SEQUENCE {
      header ItsPduHeader,
      platoonControlContainer PlatoonControlContainer
}


PlatoonControlContainer ::= SEQUENCE {
      stationType StationType,
      referencePosition ReferencePosition,
      heading Heading,
      generationDeltaTime GenerationDeltaTime,
      sequenceNumber SequenceNumber,
      platoonPosition PlatoonPosition,
      vehicleID VehicleID,
      vehicleInFrontID VehicleID OPTIONAL,
      vehicleLength VehicleLength,
      longitudinalControlContainer LongitudinalControlContainer,
      lateralControlContainer LateralControlContainer OPTIONAL,
      causeCode CauseCode OPTIONAL
      aboutToLeave BOOLEAN OPTIONAL,
      readyToLeaveInFront BOOLEAN OPTIONAL
}
```

```
LongitudinalControlContainer ::= SEQUENCE {
      grossCombinationVehicleWeight GrossCombinationVehicleWeight,
      currentLongitudinalAcceleration LongitudinalHdAcceleration,
      predictedLongitudinalAcceleration LongitudinalHdAccelerationValue,
      longitudinalSpeed Speed,
      powerToMassRatio PowerToMassRatio,
      brakeCapacity LongitudinalHdAccelerationValue,
      roadInclination RoadInclination,
      referenceSpeed Speed,
      intruderAhead VehicleAhead OPTIONAL,
      vehicleAhead VehicleAhead OPTIONAL,
      ...
}

LateralControlContainer ::= SEQUENCE {
      lateralAcceleration LateralAcceleration,
      yawRate YawRate,
      curvature Curvature,
      distanceToLeftLaneMarking LaneMarkingDistance,
      distanceToRightLaneMarking LaneMarkingDistance,
      ...
}

GrossCombinationVehicleWeight ::= INTEGER {tenKg(1), outOfRange(32766),
unavailable(32767)} (0..32767)

RoadInclination ::= INTEGER {pointOnePercentUp(1), pointOnePercentDown(-1),
unavailable(32)} (-31 .. 32)

DistanceToVehicleAhead ::= INTEGER {oneCm(1), unavailable(16383)} (0..16383)

LaneMarkingDistance ::= INTEGER {oneCm(1), unavailable(511)} (0..511)

VehicleAhead ::= SEQUENCE {
    distance DistanceToVehicleAhead,
    speed SpeedValue
}

END
```

A.4 Platoon Container

```
Platoon-Container {
    itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) en
(302637) pc (16) version (1)
}

DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

-- Similar as LongitudinalAcceleration from the ITS-Container but with
0.01m/s2 resolution
LongitudinalHdAcceleration ::= SEQUENCE {
    longitudinalAccelerationValue LongitudinalHdAccelerationValue,
    longitudinalAccelerationConfidence HdAccelerationConfidence
}

LongitudinalHdAccelerationValue ::= INTEGER {
    pointZeroOneMeterPerSecSquaredForward(1),
    pointZeroOneMeterPerSecSquaredBackward(-1),
    unavailable(1610)
} (-1600 .. 1610)

HdAccelerationConfidence ::= INTEGER {
    pointZeroOneMeterPerSecSquared(1),
    outOfRange(1022),
    unavailable(1023)
} (0 .. 1023)

PowerToMassRatio ::= INTEGER {oneWperKg(1), outOfRange(255),
unavailable(256)}(1 .. 256)

VehicleID ::= IA5String (SIZE (11..20))

PlatoonPosition ::= INTEGER {leader(1), firstFollower(2),
unavailable(32)}(1..32)

ReasonToLeave ::= ENUMERATED {unavailable(0), divert(1), weather(2),
roadCondition(3), roadWork(4), accident(5), invalidCertificate(6), merge(7),
split(8), ...}

END
```

A.5 CAM extension with platooning container

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

DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS
ItsPduHeader, CauseCode, ReferencePosition, AccelerationControl, Curvature,
CurvatureCalculationMode, Heading, LanePosition, EmergencyPriority, EmbarkationStatus,
Speed, DriveDirection, LongitudinalAcceleration, LateralAcceleration,
VerticalAcceleration, StationType, ExteriorLights, DangerousGoodsBasic,
SpecialTransportType, LightBarSirenInUse, VehicleRole, VehicleLength, VehicleWidth,
PathHistory, RoadworksSubCauseCode, ClosedLanes, TrafficRule, SpeedLimit,
SteeringWheelAngle, PerformanceClass, YawRate, ProtectedCommunicationZone,
PtActivation, Latitude, Longitude, ProtectedCommunicationZonesRSU, CenDsrcTollingZone
FROM ITS-Container {
itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts (102894) cdd
(2) version (1)
};


--  The root data frame for cooperative awareness messages

CAM ::= SEQUENCE {
    header ItsPduHeader,
    cam CoopAwareness
}

CoopAwareness ::= SEQUENCE {
    generationDeltaTime GenerationDeltaTime,
    camParameters CamParameters
}

CamParameters ::= SEQUENCE {
    basicContainer BasicContainer,
    highFrequencyContainer HighFrequencyContainer,
    lowFrequencyContainer LowFrequencyContainer OPTIONAL,
    specialVehicleContainer SpecialVehicleContainer OPTIONAL,
    ...,
    platooningContainer PlatooningContainer OPTIONAL,
    ...
}

PlatooningContainer ::= SEQUENCE {
    isJoinable BOOLEAN,
    ...
}
```

```
HighFrequencyContainer ::= CHOICE {
    basicVehicleContainerHighFrequency BasicVehicleContainerHighFrequency,
    rsuContainerHighFrequency RSUContainerHighFrequency,
    ...
}

 LowFrequencyContainer ::= CHOICE {
    basicVehicleContainerLowFrequency BasicVehicleContainerLowFrequency,
    ...
}

SpecialVehicleContainer ::= CHOICE {
    publicTransportContainer PublicTransportContainer,
    specialTransportContainer SpecialTransportContainer,
    dangerousGoodsContainer DangerousGoodsContainer,
    roadWorksContainerBasic RoadWorksContainerBasic,
    rescueContainer RescueContainer,
    emergencyContainer EmergencyContainer,
    safetyCarContainer SafetyCarContainer,
    ...
}

BasicContainer ::= SEQUENCE {
    stationType StationType,
    referencePosition ReferencePosition,
    ...
}

BasicVehicleContainerHighFrequency ::= SEQUENCE {
    heading Heading,
    speed Speed,
    driveDirection DriveDirection,
    vehicleLength VehicleLength,
    vehicleWidth VehicleWidth,
    longitudinalAcceleration LongitudinalAcceleration,
    curvature Curvature,
    curvatureCalculationMode CurvatureCalculationMode,
    yawRate YawRate,
    accelerationControl AccelerationControl OPTIONAL,
    lanePosition LanePosition OPTIONAL,
    steeringWheelAngle SteeringWheelAngle OPTIONAL,
    lateralAcceleration LateralAcceleration OPTIONAL,
    verticalAcceleration VerticalAcceleration OPTIONAL,
    performanceClass PerformanceClass OPTIONAL,
    cenDsrcTollingZone CenDsrcTollingZone OPTIONAL
}

BasicVehicleContainerLowFrequency  ::= SEQUENCE {
    vehicleRole VehicleRole,
    exteriorLights ExteriorLights,
    pathHistory PathHistory
```

```
}

PublicTransportContainer ::= SEQUENCE {
    embarkationStatus EmbarkationStatus,
    ptActivation PtActivation OPTIONAL
}

SpecialTransportContainer ::= SEQUENCE {
    specialTransportType SpecialTransportType,
    lightBarSirenInUse LightBarSirenInUse
}

DangerousGoodsContainer ::= SEQUENCE {
    dangerousGoodsBasic DangerousGoodsBasic
}

RoadWorksContainerBasic ::= SEQUENCE {
    roadworksSubCauseCode RoadworksSubCauseCode OPTIONAL,
    lightBarSirenInUse LightBarSirenInUse,
    closedLanes ClosedLanes OPTIONAL
}

RescueContainer ::= SEQUENCE {
    lightBarSirenInUse LightBarSirenInUse
}

EmergencyContainer ::= SEQUENCE {
    lightBarSirenInUse LightBarSirenInUse,
    incidentIndication CauseCode OPTIONAL,
    emergencyPriority EmergencyPriority OPTIONAL
}

SafetyCarContainer ::= SEQUENCE {
    lightBarSirenInUse LightBarSirenInUse,
    incidentIndication CauseCode OPTIONAL,
    trafficRule TrafficRule OPTIONAL,
    speedLimit SpeedLimit OPTIONAL
}

RSUContainerHighFrequency ::= SEQUENCE {
    protectedCommunicationZonesRSU ProtectedCommunicationZonesRSU OPTIONAL,
    ...
}

GenerationDeltaTime ::= INTEGER { oneMilliSec(1) } (0..65535)

END
```

APPENDIX B – ABBREVIATIONS

Abbreviation	Meaning
ACC	Adaptive Cruise Control
ASN.1	Abstract Syntax Notation One
BTP	Basic Transport Protocol
C2C-CC	CAR 2 CAR Communication Consortium
C-ACC	Cooperative Adaptive Cruise Control
C-ITS	Cooperative ITS
CA	Cooperative Awareness
CAM	Cooperative Awareness Message
CCH	Control Channel
DCC	Decentralized Congestion Control
DE	Data Element
DF	Data Frame
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short-Range Communications
CAMP	Crash Avoidance Metric Partnership
e.i.r.p	Effective Isotropic Radiated Power
ETC	Electronic Toll Collection
ETSI	European Telecommunications Standards Institute
EU	European Union
GN	GeoNetworking
GUI	Graphical User Interface
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITS	Intelligent Transport System
LOS	Line Of Sight
LLC	Logical Link Control

Abbreviation	Meaning
MAC	Medium Access Control
MAP	MapData message
OBU	Onboard Unit
OEM	Original Equipment Manufacturer
PCM	Platoon Control Message
PKI	Public Key Infrastructure
PMM	Platoon Management Message
PMC	Platooning Mode Control
RSU	Road Side Unit
SAE	SAE International, formerly the Society of Automotive Engineers
SCH	Service Channel
SDO	Standard Developing Organisation
SHB	Single Hop Broadcast
SPAT	Signal Phase and Timing message
TC	Technical Committee
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to any (where x equals either vehicle or infrastructure)
WIFI	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package