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Foreword

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

Modal verbs terminology

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Introduction

The CACC application is an extension of the in-vehicle Adaptive Cruise Control (ACC) system. It enables further reduction of the time gap with preceding vehicles compared to the ACC system, thanks to Vehicular communications.

1 Scope

The present document describes the outputs of a pre-standardization study of the Cooperative Adaptive Cruise Control (CACC) application. It consists of:

- Definition of the CACC use cases;
- Definition of CACC architecture;
- Requirement analysis of the application and the communication systems;
- Recommendations on the standardization needs for the communication layers (including facilities layer, Networking & Transport layer and access layer) in support of the CACC application;
- Recommendation on the CACC application standardization.

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.

[i.1] "G7 declaration on automated and connected driving" (09/2015).

NOTE: Also available at https://ec.europa.eu/commission/commissioners/2014-2019/bulc/announcements/g7-declaration-automated-and-connected-driving_en.

[i.2] ETSI EN 302 665 (V1.1.1): "Intelligent Transport Systems (ITS); Communications Architecture".

[i.3] SAE J3016: "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems".

[i.4] ETSI TS 101 539-3: "Intelligent Transport Systems (ITS); V2X Applications; Part 3: Longitudinal Collision Risk Warning (LCRW) application requirements specification".

[i.5] ETSI TS 101 539-2: "Intelligent Transport Systems (ITS); V2X Applications; Part 2: Intersection Collision Risk Warning (ICRW) application requirements specification".

[i.6] ETSI EN 302 637-2 (V1.4.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.7] ETSI EN 302 637-3 (V1.3.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[i.8] ISO 15622: "Intelligent Transport Systems - Adaptive Cruise Control Systems (ACC) - Performance requirements and test procedures".

[i.9] "Using Cooperative Adaptive Cruise Control (CACC) to Form High-Performance Vehicle Streams; Definitions, Literature Review and Operational Concept Alternatives".

NOTE: Available at: https://escholarship.org/uc/item/3m89p611.

[i.10] ETSI TS 103 301 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[i.11] ETSI TS 102 894-1 (V1.1.1): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 1: Facility layer structure, functional requirements and specifications".

[i.12] ISO/DIS/20035: "Intelligent Transport Systems - Cooperative Adaptive Cruise Control Systems (CACC) - Performance requirements and test procedures".

[i.13] ETSI TS 102 894-2 (V1.3.1): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary".

[i.14] Result of C-ITS Platform Phase II Release 1 (12/2017): "Security Policy & Governance Framework for Deployment and Operation of European Cooperative Intelligent Transport Systems (C-ITS)".

NOTE: Available at: https://ec.europa.eu/transport/sites/transport/files/c-its_security_policy_release_1.pdf.

[i.15] ETSI TS 103 097 (V1.3.1): "Intelligent Transport Systems (ITS); Security; Security header and certificate formats".

[i.16] AUTONET 2030 D3.2: "Specifications for the enhancement to existing LDM and cooperative communication protocol standards".

NOTE: Available at: http://www.autonet2030.eu/wp-content/uploads/2015/02/D3.2-Specifications-cooperative-communication-protocol-standards-draft-for-approval.pdf.

[i.17] DATEX II release 3.0.

NOTE: Available at: https://datex2.eu/support/getting_started.

[i.18] OCIT®-C: "Open Communication Interface for Road Traffic Control Systems - Center to Center".

NOTE: Available at: https://www.ocit.org/en/ocit/interfaces/ocit-c/.

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

active CACC vehicle: CACC vehicle with CACC at active state

CACC: V2X capable in-vehicle driving assistance system that adjusts automatically the vehicle speed to keep a target time gap with target vehicle while keeping a minimum safety distance, making use of information communicated from other vehicles and/or from the roadside infrastructure

CACC application: application layer entity that implements the CACC functionalities and application logic

CACC pair: subject vehicle and its target vehicle

CACC string: two or more CACC pairs in sequence

NOTE: 1st active CACC vehicle is the target vehicle of the 2nd active CACC vehicle, and so forth.

CACC vehicle: vehicle equipped with the system in question

NOTE 1: A CACC vehicle may or may not activate CACC at a point in time.

NOTE 2: A CACC vehicle is V2X capable.

lead vehicle: first vehicle in the upstream end of CACC string or a CACC pair

NOTE 1: The lead vehicle may not be CACC vehicle.

NOTE 2: In a CACC pair, the lead vehicle and target vehicle may be identical.

NOTE 3: Lead vehicle of a CACC string is the target vehicle of the 1st active CACC vehicle.

measured time gap: time gap between a subject vehicle and its preceding vehicle, measured at one point in time

subject vehicle: CACC vehicle with the role to follow a target vehicle

target time gap: time gap targeted by the subject vehicle for CACC operation

target vehicle: V2X capable vehicle and counterpart of the subject vehicle for the CACC application

NOTE: The target vehicle is not necessarily a CACC vehicle.

time gap: time interval between when a preceding vehicle's rear end and a following vehicle's front end passes the same location on the road surface, assuming that the following vehicle speed remains constant

V2X capable: capable of transmitting and/or receiving facilities and application layer message (e.g. CAM) with other ITS-S using wireless communications

3.2 Symbols

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

$\Delta tmin$	Minimun safety time gap
v_s	Instant speed of subject vehicle
v_t	Instant speed of TV
a_{sv}	Maximum deceleration of SV
Δt_{target}	Target time gap
Δt	Time gap between two vehicles

3.3 Abbreviations

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

ACC	Adaptive Cruise Control
BTP	Basic Transport Protocol
CA	Cooperative Awareness
CACC	Cooperative ACC
CAM	Cooperative Awareness Message
CC	Cruise Control
DATEX II	DATa EXchange II
DATEX	DATa EXchange standard for exchanging traffic information
DCC	Decentralized Congestion Control
DE	Data Element
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DF	Data Frame
GDPR	General Data Protection Regulation
GN	GeoNetworking
GN/BTP	GeoNetworking/Basic Transport Prototol
HMI	Human Machine Interface
HW/SW	Hardware/Software

I2V	Infrastructure to Vehicle
ITS	Intelligent Transport System
ITS-S	ITS Station
LDM	Local Dynamic Map
MAPEM	MAP (topology) Extended Message
OCIT-C	Open Communication InTerface for road traffic Control systems
OTA	Over-The-Air
PDU	Packet Data Unit
POTI	POsition and TIming
SAE	Society of Automotive Engineers
SAM	Service Advertisement Message
SPATEM	Signal Phase And Timing Extended Message
SRM	Signal Request Message
SSM	Signal Status Message
SSP	Service Specific Permission
SV	Subject Vehicle
SW	SoftWare
TPEG	Transport Protocol Experts Group
TS	Technical Specification
TV	Target Vehicle
UC	Use Case
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VDP	Vehicle Data Provider

4 CACC introduction

4.1 Background

In September 2015, the Transport Ministers of the G7 States and the European Commissioner for Transport agreed on a declaration on automated and connected driving [i.1] with the objective of making a significant contribution towards increasing road safety and improved mobility worldwide. The Declaration underlined the need to take appropriate steps to establish a harmonised regulatory framework. In EU, deploying vehicles without a human driver is an option only for restricted and well-defined areas. Several Member States already allow or have announced the adoption of legal acts to make the testing of automated vehicles legal, e.g. on an approved test route or in an urban environment, where the vehicle, the infrastructure and the environment are controlled.

The main motivation of CACC is to further reduce the time gap between vehicles compared to Adaptive Cruise Control (ACC) system as defined in [i.8] and to improve the response to the speed variation of the target vehicle. This would bring benefits to driver, road operator and potentially to society.

For the driver, the main benefit of CACC is related to gain the feeling of comfort, with a reduced and automatically maintained (but safe) time gap, and to the better response to the speed variation of the target vehicle. In addition, reduction of fuel consumption may be gained, thanks to the reduction of traffic jam.

For road operators, the main benefit of CACC may be related to increased road capacity and traffic efficiency. Study has shown that highway lane capacity improvement may already be observed even with low penetration rate [i.9].

The social benefits of CACC may be related to increased road safety, reduced traffic jam and or environmental benefits. Even though safety is not the primary goal of CACC, CACC can make ACC more attractive and convenient to drivers by providing behaviour that is more responsive to preceding vehicle speed changes, that gives an enhanced sense of safety because of its quicker response [i.9].

Nevertheless, special traffic management means may be needed, to optimize the traffic benefits of CACC on highway or at urban environment. For example, some simulation studies have shown CACC may even bring negative effects on lane capacity or even create traffic jams, until appropriate infrastructure support is provided. Example infrastructure support may be specific lanes assigned for CACC pair and CACC string, where road side ITS-S may provide optimized time gap and driving speed for CACC vehicles for maximizing lane capacity and traffic flow fluency.

4.2 CACC definition

CACC is an in-vehicle driving assistance system that adjusts automatically the vehicle speed to keep a target time gap Δt_{target} with a target vehicle (TV) while keeping a minimum safety distance with it. CACC makes use of data received from other vehicle ITS-Ss and/or from road side ITS-Ss via ITS network. The CACC includes at least one ITS-S application (denoted as CACC application) that implements the application logic with the services provided by the lower layers (Facilities, Networking & Transport layer, Access layer) as specified in ETSI EN 302 665 [i.2], and a set of hardware components. The CACC application processes data received from other ITS-Ss and/or from on board sensors, automatically determines vehicle speed and acceleration, and accordingly transmits control commands to longitudinal control systems (e.g. brake, accelerator). In addition, the CACC application may be operating simultaneously with other in-vehicle assistance systems or with other ITS-S applications such as pre-crash system, lateral control system, etc. CACC is connected to the in-vehicle network and has access to in-vehicle sensor data. The CACC can send control commands to acceleration/deceleration systems.

Multiple active CACC vehicles may follow each other, to form a vehicle group, denoted as CACC string in the present document. A CACC string operational environment may change dynamically e.g. a CACC string may be divided into two groups. A CACC string may be combined with another CACC string to form a new CACC string, or a CACC string may be dismissed when all vehicles leave the string.

CACC may be operated in expressway or in urban/suburban environment.

Figure 1 illustrates an example functional overview of the CACC. The dotted red rectangle illustrates the focuses of the present pre-standardization study scope. In general, the implementation of the hardware components is at the discretion of implementers. Nevertheless, the requirements defined in the present document may impact on the HW/SW implementation, for example, the compliance to the communication protocol standard is required to be considered in the development of the communication systems.

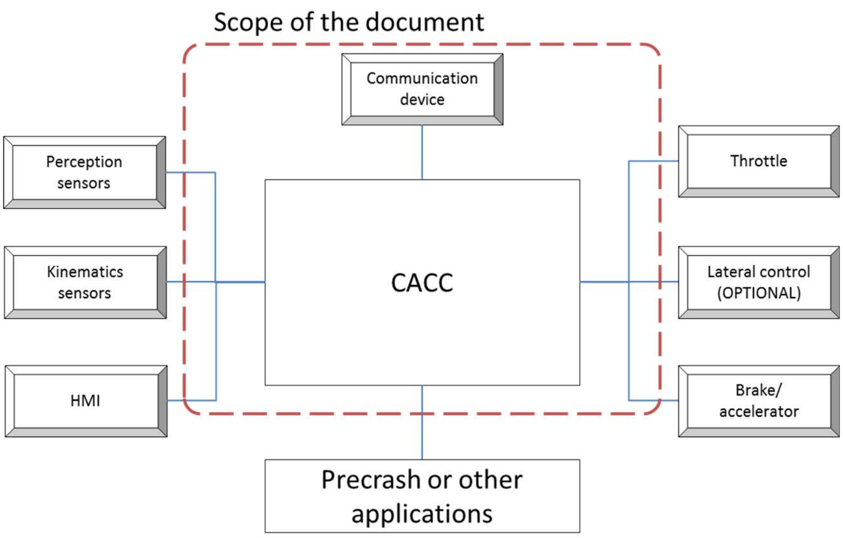


Figure 1: Scope of the document

4.3 CACC target time gap

CACC target time gap Δt_{target} is the time gap set by CACC to follow a Target Vehicle (TV). The CACC adjusts the acceleration, speed and/or brake to maintain the time gap Δt with TV to the Δt_{target}. Time gap is the time interval between when a preceding vehicle's rear end and a following vehicle's front end passes the same location on the road surface, assuming that the following vehicle's speed remains constant. The CACC target time gap is illustrated in Figure 2.

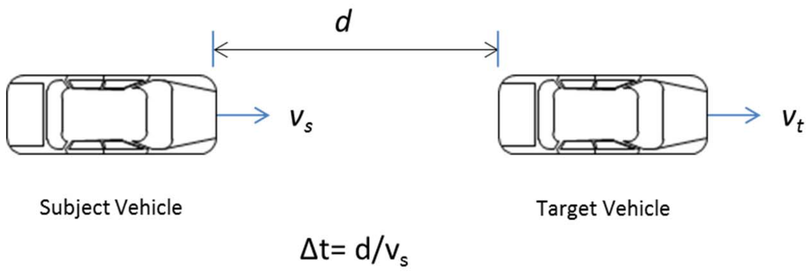


Figure 2: CACC target time gap

The Δt_{target} may be set according to different rules. In one possible setting, the Δt_{target} is proportional to vehicle speed when the vehicle speed is equal or higher than a predefined value. When v_s *is* below that value, a minimum distance d_{min} is required to be maintained. This setting rule is specified in ISO/DIS/20035 [i.12].

NOTE: In this setting rule, it is up to driver to ensure that the safety distance with TV is kept in order to avoid potential collision risk.

In another possible setting, a minimum safety time gap is required to be maintained by CACC Δt_{min}, this minimum safety time gap should be equal or higher than the time required for collision avoidance. When the Δt falls below Δt_{min}, the CACC application may be taken over by collision risk warning applications (automatic or manual), for example the Longitudinal Collision Risk Warning [i.4] or Intersection Collision Risk warning applications [i.5].

$$\Delta tmin = {|Vs - Vt|}/{asv}$$

Where:

- Δt_{min} denotes minimum safety time gap.
- v_s denotes instant speed of SV.
- v_t denotes instant speed of TV.
- a_{sv} denotes maximum deceleration of SV.

4.4 CACC and automation levels

Depending on implementation strategy, the CACC system may be used to support different automated driving modes (automation levels). In the scope of the present document, the following automation levels are used, as defined in SAE J3016 [i.3]:

- Automation level 0 as defined in SAE J3016 [i.3]. This level corresponds to the manual driving mode. CACC does not participate in this automation level.
- Automation Level 1: as defined in SAE J3016 [i.3]. The level 1 system assists driver for the acceleration/deceleration control in specific driving situations to maintain the target time gap with TV. The driver triggers, configures the Δt_{target}, terminates the CACC via specific Human Machine Interface (HMI) and when necessary, takes over the acceleration/deceleration control. A standalone CACC system is a level 1 system.
- Automation level 2: as defined in SAE J3016 [i.3]. The CACC is operating simultaneously with lateral control assistance systems such as lane keeping system, lane change assistance system. In this automation level, the CACC is triggered, configured and terminated by the human driver. Optionally, and thanks to the interaction between longitudinal and lateral assistance systems, the CACC may be temporally adjusted to support other driving assistance system e.g. the CACC configuration may be adjusted to support the automatic lane change.

- Automation level 3: as defined in SAE J3016 [i.3]. In this level, automated functions are integrated to monitor the driving environment conditions. The CACC is integrated into the automated driving system as sub component. The CACC is managed by the automated driving system without human intervention, in order to perform the automated driving task in some specific driving modes. Nevertheless, when necessary, human driver needs to take over fully or partially the driving task within a short period of time. In this case, the CACC would be switched off and taken over by the human driver.
- Automation level 4: as defined in SAE J3016 [i.3]. The CACC is integrated into the automated driving system as sub component. The CACC is managed by the automated driving system without human intervention to perform the automated driving task in some specific driving modes.
- Automation level 5: as defined in SAE J3016 [i.3]. The CACC is integrated into the automated driving system as sub component and can operate in all driving modes without direct human intervention.

The present document focuses on automation level 1 and level 2.

5 CACC use cases and operations

5.1 UC001: Follow the TV at configured Δt_{target}

5.1.1 Introduction

This use case consists of a basic operational scenario for the CACC. The CACC is configured to follow a TV with pre-configured Δt_{target}, set by driver of the SV via specific HMI.

5.1.2 Pre-conditions

- The CACC vehicle and TV are longitudinally aligned.

NOTE: Definition and description of longitudinal alignment is provided by ETSI TS 101 539-3 [i.4]. It describes that two vehicles are considered longitudinally aligned when their trajectories may lead to a forward or frontal collision whatever surface portion of the vehicles being in contact at collision time, including in curve.

- The TV is within the communication range of the CACC vehicle.

5.1.3 Actors

- Driver of the CACC vehicle.
- In vehicle sensors, including perception sensors and kinematic state sensors.
- In vehicle actuators, including throttle and/or brake.

5.1.4 Triggering condition

The use case is triggered when driver of the SV switches on the CACC via specific HMI.

5.1.5 Normal Flow

1) Driver switches on CACC.
2) Driver configures the target time gap Δt_{target}. The Δt_{target} value range may be set according to one of the setting rules as introduced in clause 4.3.
3) CACC receives position and kinematic state data from the vehicles in the proximity.
4) CACC receives in-vehicle sensor data from in vehicle network.

5) CACC application processes the received data and checks the relevance of the received data with regards to SV's itinerary, e.g. driving direction, upstream/downstream relevance, etc.

6) CACC application identifies the TV.

7) Optionally, CACC estimates the kinematic state of the TV using Collective Perception Service. If additional perception sensor data is available, data fusion functionality is used for data processing from different sources about the TV.

8) CACC calculates periodically the measured time gap with the target vehicle. The time gap calculation is realized by comparing the kinematic data of the target vehicle and the subject vehicle.

9) If necessary, CACC engages the brake or accelerator to adjust to the target time gap. Maximum brake value is defined in ISO/DIS/20035 [i.12].

Termination of use case:

1) Driver of the SV switches off CACC via specific HMI.

2) CACC system is switched to stop state or to CC state (cruise control).

5.1.6 Termination condition

The use case is terminated when driver of the SV switches off CACC via specific HMI.

Alternatively, the use case may be terminated when, e.g. if no TV is identified when a predefined timer is expired. In such case, the termination of the CACC should be informed to driver via specific HMI, or a Cruise control is triggered and informed to driver to maintain the vehicle at a set speed.

5.1.7 Use case diagram and use case illustration

This CACC use case corresponds to the automation level 1 as described in clause 4.4 of the present document. The use case diagram is illustrated in Figure 3. An example use case scenario is given in Figure 4.

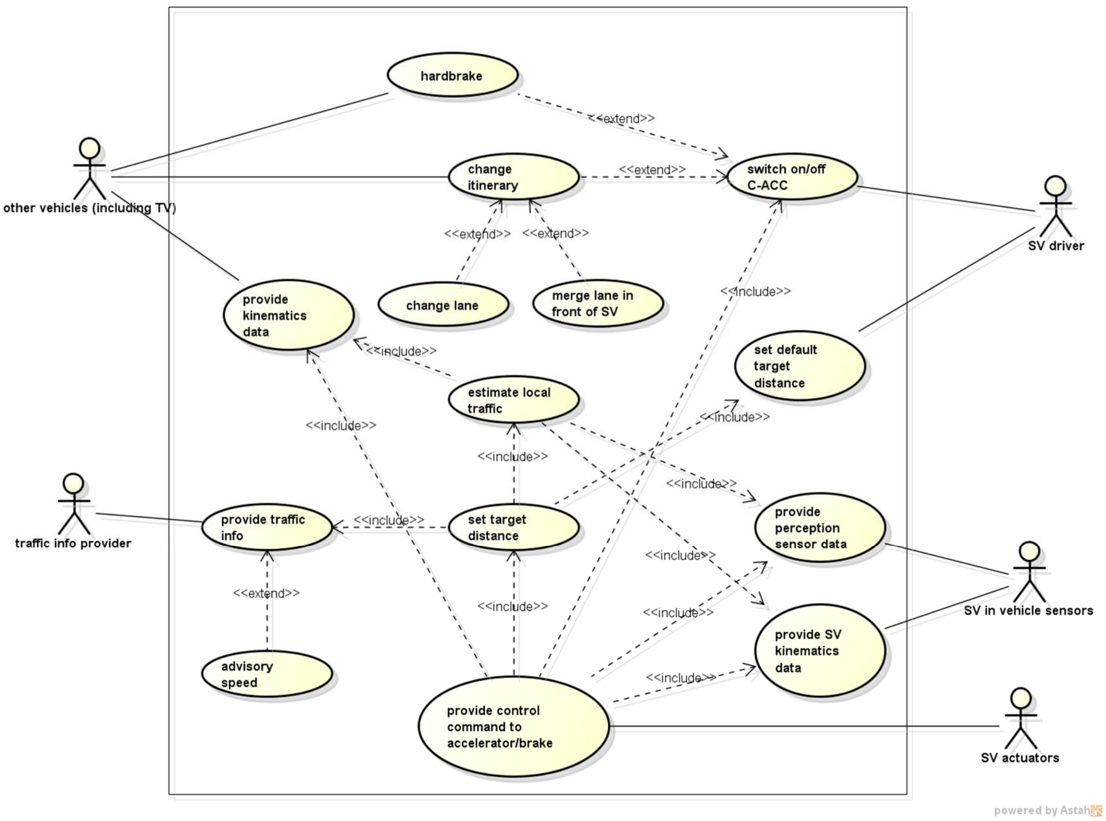
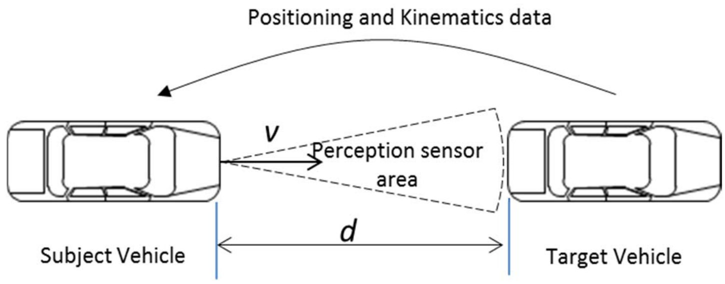


Figure 3: Use case diagram: follow TV with configured time gap



$$\Delta t = \Delta t_{target} = d/v$$

Figure 4: Example use case scenario

5.1.8 Alternative flow

Interfering vehicle detected (cut in vehicle detected):

1) CACC detects another vehicle that may enter between the SV and the TV e.g. by changing the lane. A cut-in vehicle is detected.

2) CACC application processes the data, checks the relevance of the cut-in vehicle with regards to the SV.

3) If the interference is confirmed and the relevance is false (for example the cut-in vehicle will leave the road in short time), CACC should be switched to standby mode and keep safety distance with the cut-in vehicle, until the interference disappears.

4) If the interference is confirmed and the relevance is true, the CACC should re-identify the cut-in vehicle as the TV and processes the data as normal flow.

NOTE 1: In case the cut in vehicle is V2X equipped.

5) If the standby mode is triggered for a pre-defined time period, CACC may be switched to stop mode.

6) If the standby mode and/or stop mode is triggered, the driver should be informed.

No TV detected:

1) If no TV is identified for a pre-defined time period, CACC may be switched to standby mode or CC mode.

NOTE 2: The no TV detection may happen in case of communication failure.

NOTE 3: Communication failure may represent safety risk to CACC, exception handling of this failure is out of scope of the present document.

2) If the standby mode is triggered for a pre-defined time period, CACC may be switched to stop mode.

3) CACC system is switched to standby mode or stop mode, the driver should be informed to take over the acceleration/deceleration control.

TV lost:

1) If the TV is lost, CACC may be switched to standby mode/ACC/CC. The TV lost may happen if the TV has changed the itinerary, changed the lane, or the SV has changed the itinerary or changed the lane. In addition, the TV lost may happen in case of communication failure.

2) During the standby mode, the CACC application continues to process the received data and/or sensor data, to identify potential new TV.

3) If new TV is identified, back to normal flow.

4) If the standby mode persists for a predefined time period, CACC may be switched to the stop mode.

5) If CACC is switched to or standby mode or stop mode, the driver should be informed to take over the acceleration/deceleration control.

Collision risk detected:

1) If the TV brakes hardly, CACC vehicle detects a potential collision risk.

2) The collision risk application at CACC vehicle requires automatic braking, or driver's intervention to avoid collision risk e.g. hard brake or change the lane, or precrash application is triggered in case collision cannot be avoided. The Δt_{target} cannot be kept any more.

3) The CACC is switched off temporarily to standby mode.

4) If the standby mode persists for a predefined time period, CACC may be switched to the stop mode.

5) If CACC is switched to either standby mode or stop mode, the driver should be informed to take over the acceleration/deceleration control or that automatic collision risk avoidance system may take over CACC.

5.1.9 Post-conditions

The time gap with TV is maintained as configured by driver.

5.2 UC002: Follow the TV at automatically adjusted Δt_{target}

5.2.1 Introduction

In this use case, a bottleneck such as traffic jam or bad weather conditions is located in the downstream traffic of the subject vehicle, the traffic flow capacity drops. CACC dynamically adjusts the Δt_{target} with the TV to further reduce the inter vehicle distance to contribute to the traffic flow efficiency.

5.2.2 Pre-conditions

- The CACC vehicle and the TV are longitudinally aligned.

NOTE: Definition and description of longitudinal alignment is provided by ETSI TS 101 539-3 [i.4].

- The TV is within the communication range of the CACC vehicle.
- The average traffic flow speed in the downstream traffic of SV is reduced.

5.2.3 Actors

- Driver of the CACC vehicle.
- ITS-S implemented in the surrounding vehicles.
- Traffic information provider (may be a vehicle ITS-S, a road side ITS-S or a central ITS-S).
- In vehicle sensors, including perception sensors and kinematic state sensors.
- In vehicle actuators, including throttle and/or brake.

5.2.4 Triggering condition

The use case is triggered when:

1) driver of the SV switches on CACC via specific HMI; and

2) optionally, the CACC vehicle receives downstream traffic information from traffic information provider.

5.2.5 Termination condition

The use case is terminated when driver of the SV switches off CACC via specific HMI.

Alternatively, the use case may also be terminated based on specific system configuration parameters, e.g. when no TV is identified when a predefined timer is expired. In such case, the termination of the CACC system should be informed to driver via specific HMI.

5.2.6 Use case diagram and use case illustration

This CACC use case corresponds to the automation level 1 as described in clause 4.4 of the present document. The use case diagram for the normal flow is illustrated in Figure 5. An example use case scenario is given in Figure 6.

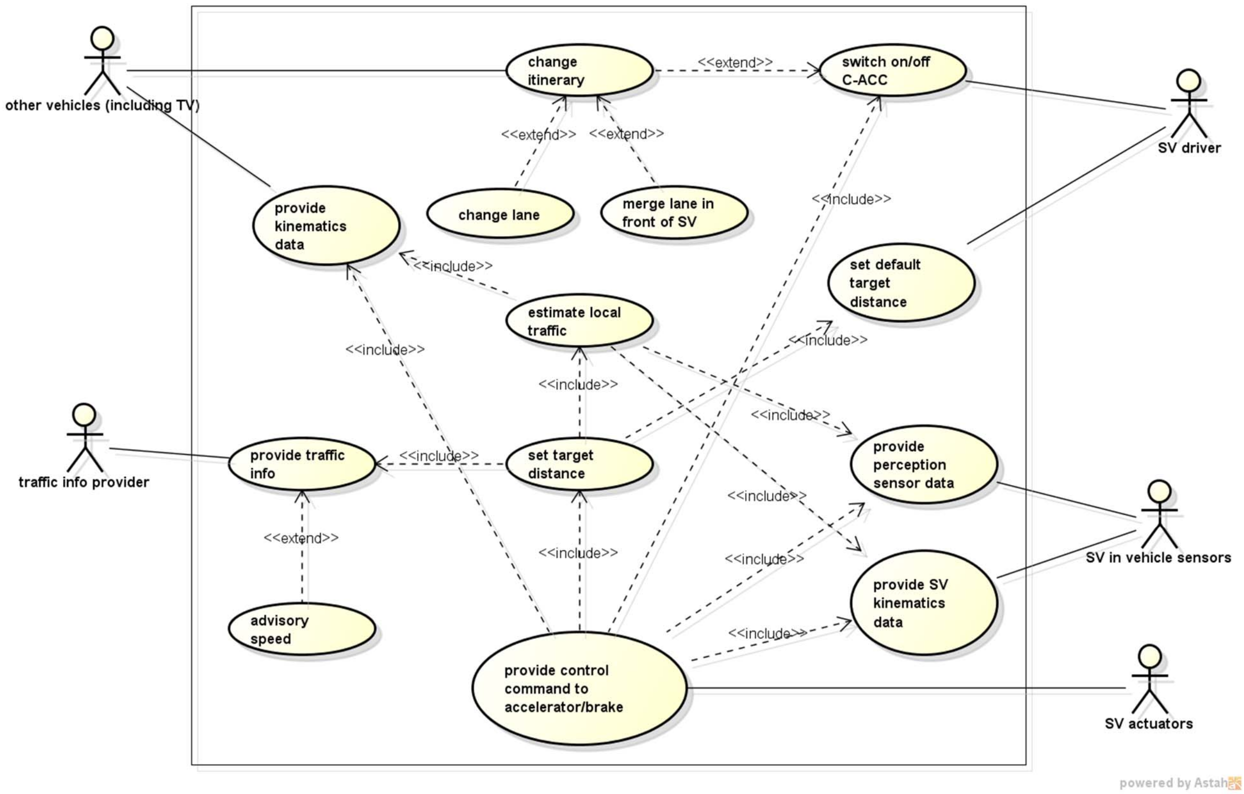


Figure 5: Use case diagram: follow TV with dynamically configured distance

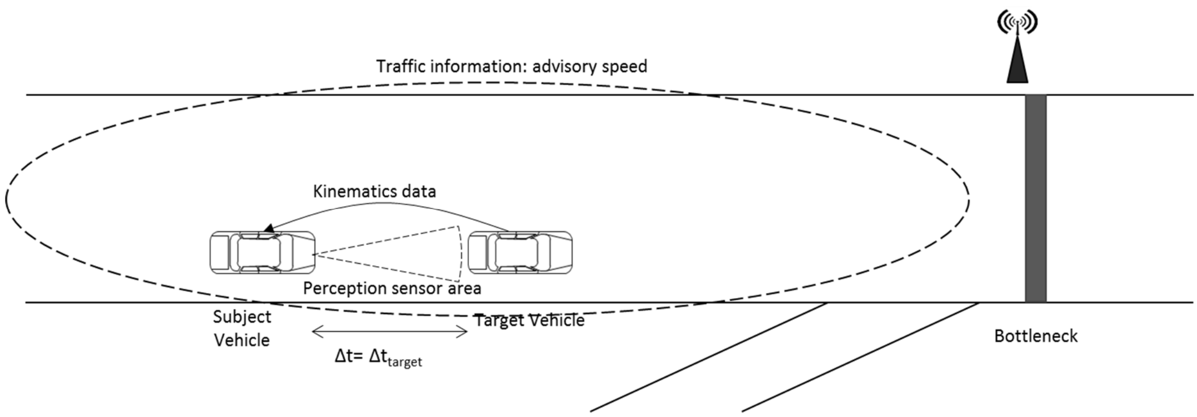


Figure 6: Example use case scenario

5.2.7 Normal Flow

1) Driver switches on CACC and sets a default Δt_{target}.
2) The CACC vehicle receives traffic information from traffic information provider, informing it about a bottleneck in the downstream traffic with a reduced advisory traffic speed.
3) The CACC dynamically configures Δt_{target} according to the received traffic information.
4) Idem of step 3) to 9) in use case 001.
5) The CACC informs the currently set Δt_{target} to driver with specific HMI.

Termination of use case:

1) Idem to use case 001.

5.2.8 Alternative flow

In addition to the ones identified in UC001, the following alternative flow applies.

Non-reception of traffic information:

1) CACC estimates the local traffic average speed based on received kinematics state data from other vehicles.
2) CACC estimates the Δt_{target} according to its estimation or use the default Δt_{target} as set by driver.
3) CACC informs the currently set Δt_{target} to driver with specific HMI.

5.2.9 Post-conditions

The inter distance with preceding vehicle is dynamically adjusted according to the local traffic environment.

5.3 UC003: Single lane CACC string

5.3.1 Introduction

In this use case, more than two active CACC vehicles are following with each other to form a single lane CACC string.

5.3.2 Pre-conditions

- More than two active CACC vehicles are longitudinally aligned.
- CACC vehicles are within the communication range with its direct neighbour CACC vehicles.

5.3.3 Actors

- Driver of the CACC equipped vehicles.
- ITS-S implemented in the preceding vehicle of the first CACC equipped vehicle.

5.3.4 Triggering condition

The use case is triggered when CACC identifies a TV and discovers (via receiving message) that the TV is in CACC active state.

5.3.5 Termination condition

The use case is terminated when the CACC vehicle leaves the single lane CACC string by switching off the CACC or changes its itinerary or lane.

Alternatively, the use case may be terminated when SV discovers (via receiving messages) that its TV is not any more in a CACC active state.

NOTE 1: Non-reception of such message may indicate that the CACC string has been dissolved.

NOTE 2: CACC may switch to UC001 or UC002 in case that CACC string is dissolved.

5.3.6 Use case diagram and use case illustration

This CACC use case corresponds to the automation level 1 as described in clause 4.4 of the present document.

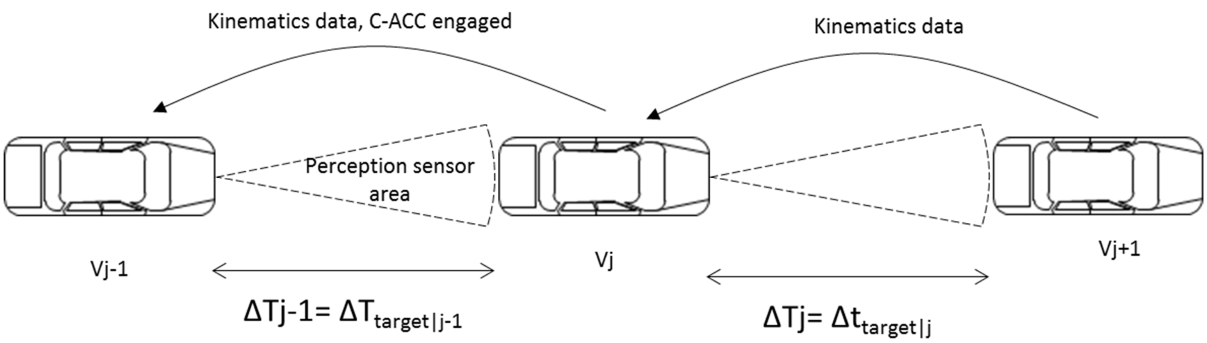


Figure 7: Example use case scenario

5.3.7 Normal Flow

1) Driver of the SV switches on CACC.

2) SV receives message from vehicles nearby, it discovers that one of vehicles is at CACC active mode.

3) CACC informs driver the possibility of a CACC string and indicate the vehicle to follow.

4) Driver of the SV position the SV after the TV.

5) The Δt_{target} is set either by driver or by CACC. Δt_{target} setting may take the Δt_{target} set by the TV into account.

6) The SV includes the CACC active mode information in the message and transmits it.

7) The vehicle operates CACC as defined in use case 001 or in use case 002.

Termination of use case:

1) CACC application checks the messages received from TV, then discovers that the TV is not any more at active mode.

2) CACC switch to UC001 or UC002.

5.3.8 Alternative flow

In addition to the ones identified in UC001 and in UC002, the following alternative flow applies.

Limited length may be needed, when the average speed of the string is lower than the free flow speed. This would potentially become a new traffic flow bottleneck, and in addition would become less stable in terms of "cut in" case and for frequent "join" and "leave" case.

In addition, length management is also needed for the stability of the CACC string. The measured time gap between vehicles in a CACC string is inevitably fluctuated due to the practical difficulties even though the amount of fluctuation can be reduced by CACC compared to ACC. The fluctuation of the measured time gap requires that a subject vehicle performs more aggressive acceleration/deceleration control than its target vehicle to keep a target time gap constantly, and this effect is accumulatively increased as the length of a CACC string is increased. For example, the required braking at the end of the string would be accumulated increase, in case lead vehicle does a hard brake, so this would result in safety issue for too long CACC strings.

In case of CACC string with limited length:

1) The CACC vehicle receives a message indicating the maximum length allowed from CACC vehicle(s) of a CACC string or road side ITS-S(s).

NOTE: The CACC string length limit can be the maximum allowed number of vehicles in a CACC string, or the maximum allowed distance of a CACC string, i.e. the geometrical distance between the 1st vehicle (lead vehicle) and the last vehicle of a CACC string.

2) The CACC system estimates the total length of CACC string if it would join the string.

3) In case the total length exceeds the maximum value, CACC should refrain from joining the CACC string.

4) CACC should inform driver of unsuccessful joining to the CACC string.

In case string is divided:

1) One vehicle in CACC string stop following its TV and leaves the CACC string, a hole is created in CACC string.

2) The follow up vehicle may follow the leaving vehicle, a CACC string is divided.

3) Or the follow up vehicles reidentifies a TV and stays in the string.

5.3.9 Post-conditions

A one lane string is formed and operated.

5.4 UC004: Single lane CACC string support service provided by road side

5.4.1 Introduction

In this use case, road side ITS-S operates a road side CACC string support service and transmits information to CACC vehicles to manage the CACC string operation.

The benefits of this use case are that a CACC vehicle is encouraged to use a prioritized lane reserved for a CACC string or for automated driving (like car pool lane or reserved lane for public transport).

5.4.2 Pre-conditions

- More than one active CACC vehicles are driving in the same lane.
- CACC vehicles are within the communication range with its direct neighbour CACC vehicles.
- Road side ITS-S is authorized to provide CACC string support service.
- The area covered by road side service is appropriate to operate CACC string.

5.4.3 Actors

- Driver of the CACC equipped vehicles.

- Road side CACC string support service provider.
- Traffic info provider (optional).

5.4.4 Triggering condition

The use case is triggered by the driver of the CACC vehicle confirming that he/she will join the CACC string support service provided by the road side service provider.

5.4.5 Termination condition

The use case is terminated when the CACC vehicle leaves the single lane CACC string by e.g. switching off the CACC or changes its itinerary/lane.

Alternatively, the use case may also be terminated when the CACC vehicle leaves the service area provided by road side service provider.

5.4.6 Use case diagram and use case illustration

This CACC use case corresponds to the automation level 1 as described in clause 4.4 of the present document.

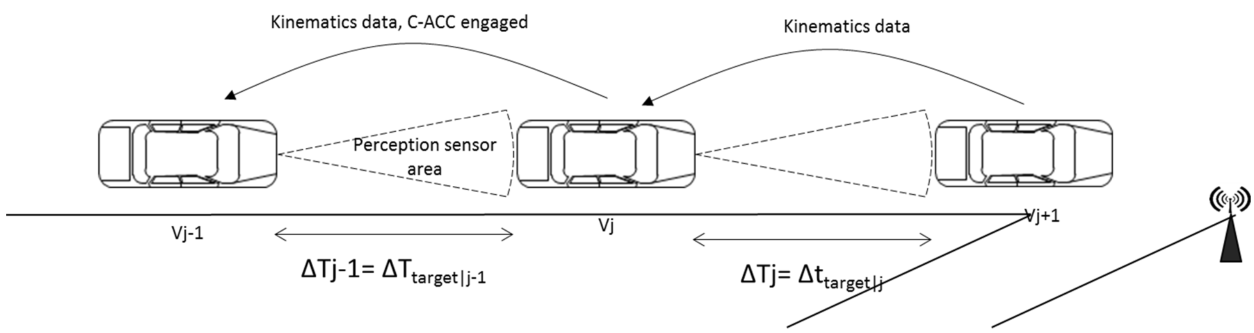


Figure 8: Example use case scenario

5.4.7 Normal Flow

1) CACC vehicle receives the service announcement from a road side ITS-S, announcing the availability of the road side CACC string service.
2) CACC application informs driver of the service availability.
3) Driver confirms the joining of CACC string via specific HMI.
4) SV joins the CACC string as described in UC003.

Termination of use case:

1) CACC leave the service area.
2) CACC application informs driver.
3) Driver switches off CACC.

5.4.8 Alternative flow

In case of CACC string with limited length:

1) The CACC vehicle receives a message indicating the maximum length allowed.
2) The CACC system estimates the total length of CACC string.
3) In case the total length exceeds the maximum value, CACC should refrain from joining the CACC string.
4) The CACC system should inform the driver when joining to the CACC string is not successful.

5.4.9 Post-conditions

A one lane string is formed and operated within the service area in which road side CACC string service is provided.

5.5 UC005: Co-operation of lane keeping assistance system and CACC

5.5.1 Introduction

In this use case, the CACC and lateral control assistance system is working simultaneously. This provides a level 2 automation function.

5.5.2 Pre-conditions

The CACC vehicle and the TV are longitudinally aligned.

The TV is within the communication range of the CACC vehicle.

SV is equipped with lane keeping assistance system.

5.5.3 Actors

Driver of the CACC vehicle.

In vehicle sensors, including perception sensors and kinematic state sensors.

In vehicle actuators, including throttle and/or brake.

5.5.4 Triggering condition

This use case is triggered, when driver switches on the lane keeping assistance system and CACC.

5.5.5 Termination condition

The use case is terminated when driver of the ego vehicle switches off the CACC system via specific HMI.

Alternatively, the use case may also be terminated based on specific system configuration parameters, e.g. when no target vehicle is identified when a predefined timer is expired. In such case the driver will be informed via a specific HMI.

5.5.6 Normal Flow

1) CACC driver switches on the level 2 assistance system, including CACC and lane keeping assistance.
2) Normal flow as one of the UC001, UC002, UC003 or UC004.
3) The TV identification step should identify a TV within the same lane of SV.

4) The lane keeping assistance system enables SV follows TV with automatic lane keeping function.

Termination of the use case:

1) Driver of CACC system switch off the level 2 assistance system.

5.5.7 Alternative flow

In case the driver wishes to take over the lateral control:

1) CACC application recalculates the $\Delta t_{target,}$ normally the Δt_{target} should be increased with an estimated driver take over time.

2) CACC adjusts the Δt_{target} and informs driver that take-over may be done.

3) After take-over, if driver starts the lane change, the CACC is switched to standby mode and identifies the potential TV in another lane.

4) After lane change is finalized and if a TV is identified, CACC is switched to operation mode with new TV.

In case TV changes the lane, the lane keeping system of SV will maintain the vehicle is the same lane, CACC may be switched to standby mode.

NOTE: In case TV is also equipped with lane keeping assistance system, this use case may bring higher comfort to driver at SV, since this will avoid frequent lane change of TV.

5.5.8 Post-conditions

Automatic driving and following of TV in one lane.

5.6 UC006: Co-operation of lane change assistance system and CACC

5.6.1 Introduction

In this use case, the SV and TV may realize lane change manoeuvring together, CACC is used for following the TV. This provides a level 2 automation function.

5.6.2 Pre-conditions

The CACC vehicle and the TV are longitudinally aligned.

The TV is within the communication range of the CACC vehicle.

SV and TV are both equipped with lane change assistance system.

5.6.3 Actors

Driver of the CACC vehicle.

In vehicle sensors, including perception sensors and kinematic state sensors.

In vehicle actuators, including throttle and/or brake.

5.6.4 Triggering condition

The TV engages lane change assistance system.

5.6.5 Termination condition

The use case is terminated when both SV and TV finalize the lane change.

5.6.6 Normal Flow

1) CACC driver switches on the level 2 assistance system, including CACC and lane change assistance system.
2) SV receives a message and discovers that TV has engaged the lane change assistance system for lane change.
3) CACC application processes the data received from TV, such as its predicted path, and the data received from sensors.
4) Lane change assistance system of SV estimates that space at the target lane is sufficient to realize lane change by following TV.
5) CACC calculates the Δt_{target} to follow the TV for lane change.
6) SV follows the TV until the lane change is finalized.

Termination of the use case:

1) SV finalize the lane change.
2) SV continues to follow TV as in UC 001.

5.6.7 Alternative flow

In case the lane change assistance system determines there is no sufficient space at target lane for SV to realize lane change:

1) Driver is informed to take over the lateral control.
2) CACC application recalculates the $\Delta t_{target.}$ (it should be increased to cover the take-over time).
3) After take-over, if TV has changed the lane, the CACC is switched to standby mode.

5.6.8 Post-conditions

Both TV and SV have changed the lane, SV continues to follow TV using CACC.

5.7 UC007: CACC pair passing through I2V equipped traffic lights

5.7.1 Introduction

In this use case, a 1st vehicle passes through intersections equipped with traffic lights, by making use of data transmitted from road side ITS-S. A second vehicle sets the 1st vehicle as TV and follows it to pass the intersection as CACC pair.

5.7.2 Pre-conditions

A CACC pair is formed.

5.7.3 Actors

Driver of the CACC vehicle.

In vehicle sensors, including perception sensors and kinematic state sensors.

In vehicle actuators, including throttle and/or brake.

5.7.4 Triggering condition

The CACC pair is approaching to a traffic light equipped intersection.

5.7.5 Termination condition

The use case is terminated after the CACC pair has passed the intersection. It may go to UC001 or UC002.

5.7.6 Use case diagram and use case illustration

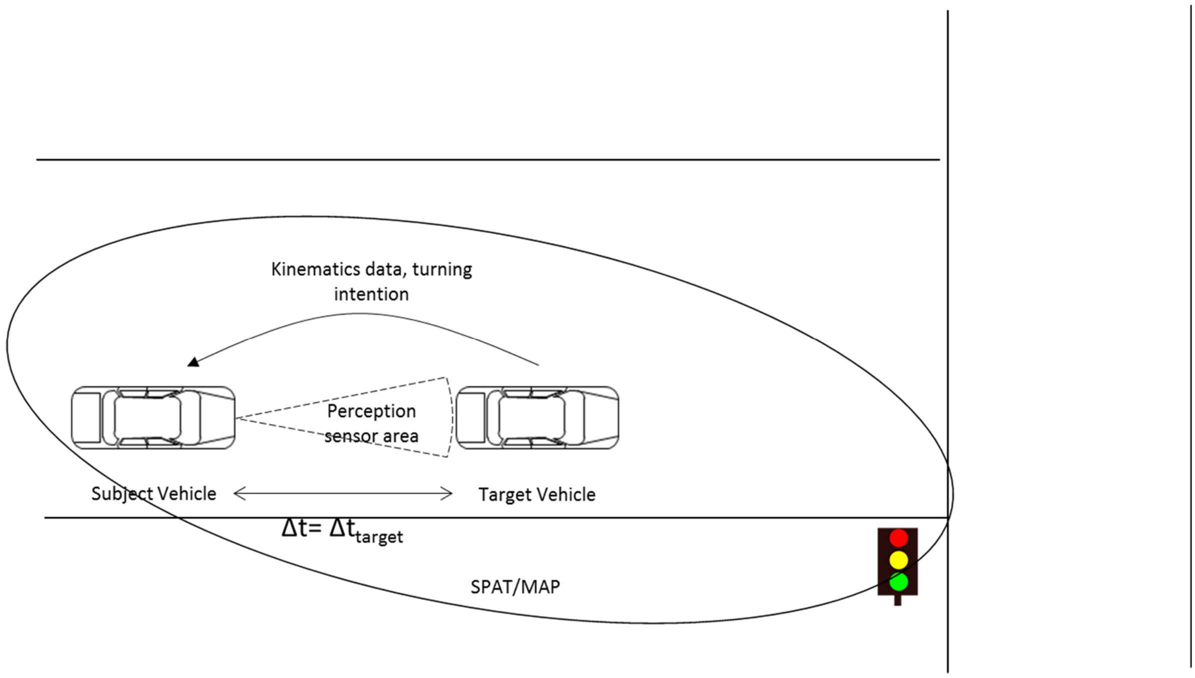


Figure 9: Example use case scenario

5.7.7 Normal Flow

1) CACC receives SPATEM/MAPEM from road side ITS-S.
2) CACC receives crossing intention information of the TV at intersection.
3) CACC application determines whether or not the crossing intention of SV is the same as TV.
4) If yes, CACC determines the $\Delta t_{target.}$to pass through the intersection, based on the remaining traffic signal phase and timing.

Termination of the use case:

1) The CACC pair passes through the intersection.

5.7.8 Alternative flow

In case the TV needs to stop in front of traffic light:

1) CACC reduces the SV speed and stop behinds the TV.
2) The use case is resumed when the traffic light authorization is given to TV.

In case the TV crossing intention is different from SV:

1) CACC system is switched to off mode and driver is informed.

2) Driver takes over the control.

In case remaining time does not allow SV to pass by following the TV:

1) CACC system is switched to standby mode and driver is informed.

2) Driver takes over the control and stops in front of traffic light.

5.7.9 Post-conditions

The CACC pair passes through the intersection.

6 CACC architecture

6.1 Functional architecture

The functional architecture of the CACC is illustrated in Figure 10. The main functional blocks of the CACC are the following:

- Message handler: it manages the generation, encode/decode, reception and transmission of C-ITS messages for the usage of CACC application.
- TV identifier: it identifies the TV based on data available from message handler, vehicle status monitor and environment monitoring.
- Vehicle status monitor: it monitors the vehicle kinematics status and status of other in vehicle systems e.g. lateral control assistance systems.
- Environment monitor: it monitors the vehicle surrounding environment e.g. traffic status, road topology, other vehicles' status, etc.
- CACC logic manger: it manages the CACC logic, e.g. transition between different CACC application machine state, joining/leaving decision to CACC string, set up CACC parameters (e.g. target time gap), etc.
- Motion planner: based on CACC parameters set by CACC logic manager, this function makes decision of vehicle motion and potentially vehicle trajectory or vehicle manoeuvring e.g. acceleration value, planned speed, etc.
- Actuator control manager: it manages and generates control command to corresponding vehicle actuators according to the motion planner results.

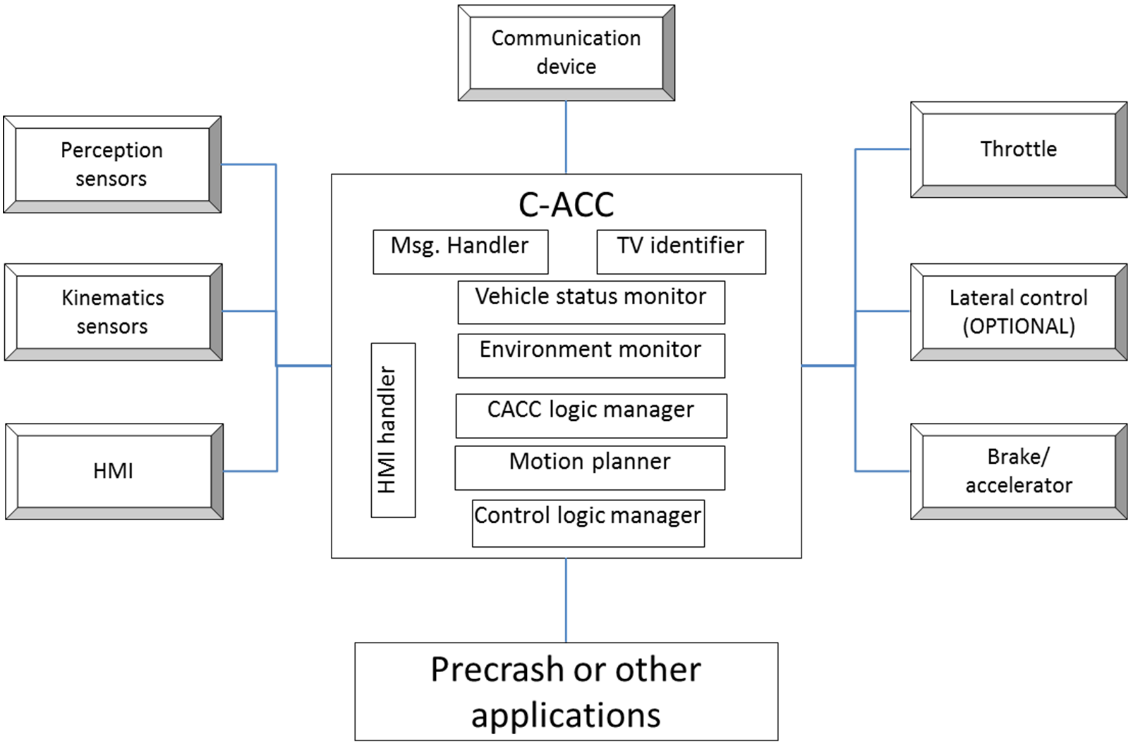


Figure 10: CACC Functional architecture

6.2 Information architecture

Figure 11 illustrates an example of CACC information architecture. At each subject vehicle, CACC receives information of other vehicles from ITS access layer (OTA: Over the Air) interface. SV also process its own sensor data received from in vehicle network, such as perception sensor data, or via Vehicle Data Provider (VDP). The output results of CACC application is translated to certain control command and transmitted to corresponding vehicle actuators. As result, the subject vehicle maintains the time gap to TV according to the set target time gap.

Messages are exchanged between vehicles (V2V messages including subject vehicle and target vehicle). The content and message exchange protocols are described in clause 9.1 of the present document.

Optionally, vehicle ITS-S and road side ITS-S may exchange the following information to support the use cases described in clause 5:

- Traffic information (e.g. traffic jam, speed limit, average speed, advisory speed, etc.) transmitted from road side ITS-S to vehicle ITS-S in the surrounding area. CACC logic manger may take such information into account in its application operation, e.g. to determine the $\Delta t_{target.}$ and/or vehicle target speed according to the surrounding traffic.

- Road topology information (e.g. curve, intersection topology) transmitted from road side ITS-S to vehicle ITS-S in the surrounding area. CACC motion planner may take such information into account to determine the vehicle trajectory. The road topology message and protocols are specified in ETSI TS 103 301 [i.10].

- Traffic light status and timing information transmitted from road side ITS-S to vehicle ITS-S in the surrounding area. CACC application at the subject vehicle may take such information into account in its application logic, e.g. to determine the Δt_{target} and/or vehicle manoeuvring; The SPATEM message and protocols are specified in [i.10].

- SSM (Signal Status Message) and SRM (Signal Request Message) (as specified in ETSI TS 103 301 [i.10]) so that traffic light controller can support CACC passing through the intersection without dissolving.

- CACC parameter information transmitted from road side ITS-S to vehicle ITS-S in the surrounding area. This may happen in case road operator provides services to manage the CACC string on a certain road segment as described in UC004 (see clause 5.4).

A road side ITS-S may provide the above-mentioned services standalone, or supported by a central ITS-S. The central ITS-S may either receive vehicle probe information collected by road side ITS-S or directly from vehicle ITS-S for the purpose of traffic monitoring, or provide traffic information, road topology information, service information, etc. to road side ITS-S within the relevant area or directly to vehicle ITS-S. Examples of these messages and exchange protocols from and to the central ITS-S are DATEX II as specified in [i.17], OCIT-C as specified in [i.18], and in ISO 21219 [i.12] multi-parts standards series.

NOTE: Extensions of DATEX II and OCIT®-C are out of scope of the present document.

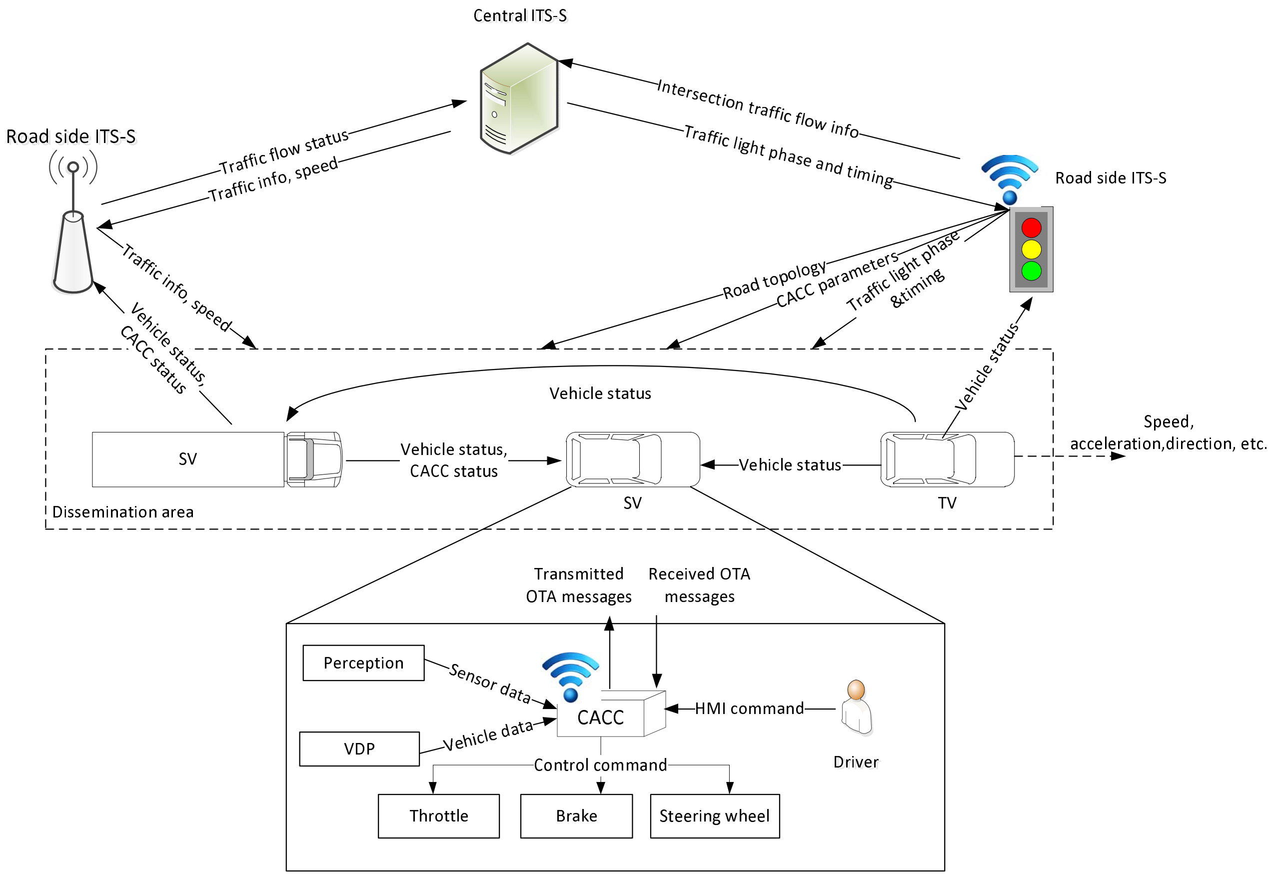


Figure 11: CACC information architecture

6.3 Communication architecture

Figure 12 illustrates the CACC positioning in the ITS reference communication architecture as specified in ETSI EN 302 665 [i.2] for a subject vehicle and/or a road side ITS-S. CACC is supported by components in different ITS layers, described as following:

- Application layer: the CACC application is the application layer entity that manages the CACC logic. In the present document, CACC application functionalities are classified into CACC transmission mode and CACC receiving mode. This application entity will be present in a road side ITS-S, only when this road side ITS-S provide road side services to CACC.

- Facilities layer: multiple facilities components may be needed to support the CACC application, including the application support facilities, information support facilities and communication support facilities as defined in ETSI TS 102 894-1 [i.11]:

  - CA basic service: it manages the transmission and reception of Cooperative Awareness Message (CAM) from and to vehicle ITS-S. The CA basic service is specified in ETSI EN 302 637-2 [i.6]. The present document describes the extension required to support CACC application.

- DEN basic service: it manages the transmission and reception of Decentralized Environmental Notification Message (DENM) from and to vehicle ITS-S or road side ITS-S. The DEN basic service is specified in ETSI EN 302 637-3 [i.7]. The present document describes the extension required to support CACC application.
- Other messages: It may refer to one or more than one facilities entities that manage the transmission and reception of messages other than CAM and DENM and as described in clause 9.1 of the present document.
- POTI: The Position and Time facility provides the position and time information in real time for CACC application.
- LDM: The Local Dynamic Map is database that stores/updates the facilities layer data and delete the outdated/invalid facilities layer data. It provides a database to be accessible to application layer for application running.
- VDP: The Vehicle Data Provider receives in vehicle sensor data in real time from in vehicle networks to support CACC application. The data provided by VDP may be stored in LDM.
- Vehicle control: this facilities layer entity supports CACC application by transmitting control command directly to vehicle actuators or to other in vehicle assistance system via in-vehicle network.

• Networking & Transport layer: including GN/BTP protocol stack and/or Ipv6 protocol stack.

• Access layer: including one or more than one access layer technologies such as ITS G5, LTE, LTE V2X, 3G, etc.

• Management entity: including mainly Decentralized Congestion Control (for ITS G5), and/or multi-channel management for access layer technologies.

• Security entity: including mainly C-ITS security and vehicle internal network security.

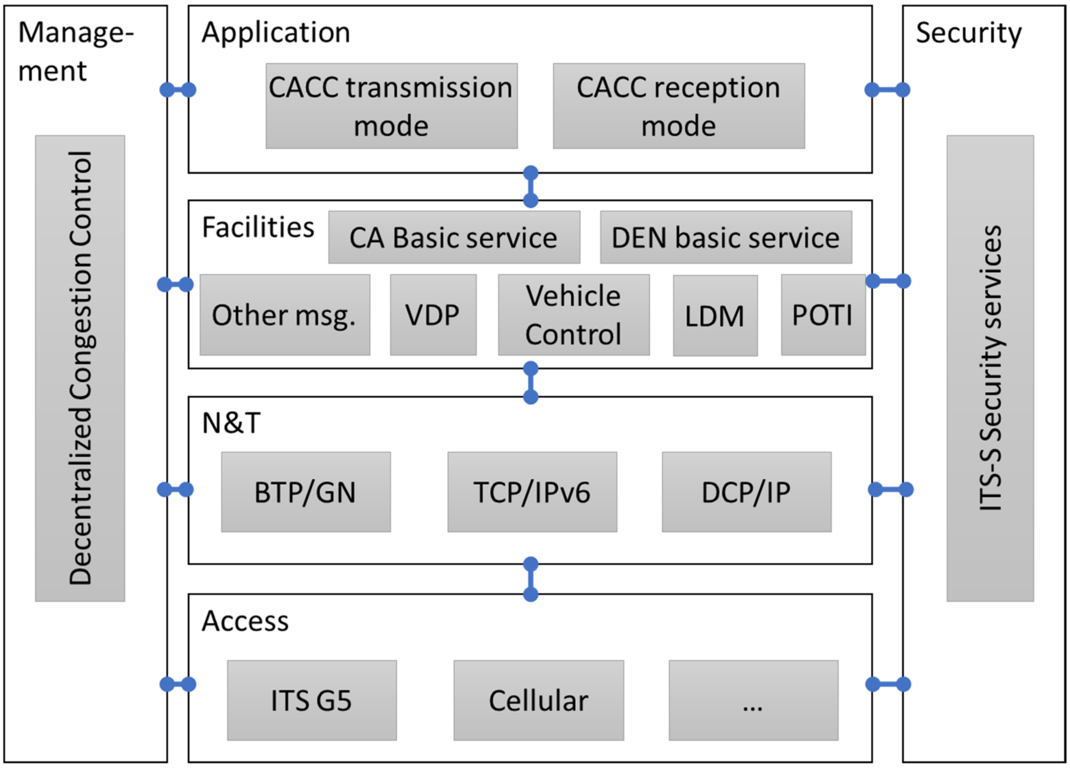


Figure 12: CACC communication architecture

7 Functional requirements

7.1 Application layer

The following potential functional requirements may apply to CACC applications.

ID	Description	UC0 01	UC0 02	UC0 03	UC0 04	UC0 05	UC0 06	UC0 07
FR1.	CACC should be able to identify a TV	x	x	x	x	x	x	x
FR2.	CACC should estimate time gap to the TV	x	x	x	x	x	x	x
FR3.	CACC should calculate the Δt_{target} value		x	x	x	x	x	x
FR4.	CACC should be able to send control command to longitudinal control	x	x	x	x	x	x	x
FR5.	CACC should monitor lane change intention of SV	x	x	x			x	x
FR6.	CACC should monitor lane change intention of TV	x	x	x	x	x	x	x
FR7.	CACC should set the minimum safety distance	x	x	x	x	x	x	x
FR8.	The CACC should process SPAT/MAP/IVI messages							x
FR9.	The CACC should estimate the path relevance of TV with its own predicted path	x	x	x		x	x	x
FR10.	The CACC should estimate if remaining traffic light phase and timing allows itself to pass through the interaction							x
FR11.	The CACC should judge if driver takeover is necessary	x	x	x	x	x	x	x
FR12.	The CACC should provide interface to HMI	x	x	x	x	x	x	x
FR13.	The CACC-HMI interface should include "warning" and "information" type of message	x	x	x	x	x	x	x
FR14.	The CACC should inform driver of CACC on/off state	x	x	x	x	x	x	x
FR15.	The CACC may inform driver of other states (ACC, Cruise, etc.)	x	x	x	x	x	x	x

7.2 Facilities layer

FR16.	The CACC should implement CA basic service	x	x	x	x	x	x	x
FR17.	The CACC may implement DEN basic service			x	x			
FR18.	The CACC should implement POTI service	x	x	x	x	x	x	x
FR19.	The CACC should implement VDP basic service	x	x	x	x	x	x	x
FR20.	The CACC may implement collective perception service	x	x	x	x	x	x	x
FR21.	The CACC should implement Infrastructure Message service				x			x
FR22.	The CACC may implement LDM service	x	x	x	x	x	x	x

7.3 Networking & Transport layer

FR23.	ITS-S should implement Single Hop Broadcasting GN protocol	x	x	x	x	x	x	x
FR24.	The GN packet life time should be set to 1 s	x	x	x	x	x	x	x

7.4 Access layer

FR25.	The SV and TV should use the same access technologies for C-ITS message exchange	x	x	x	x	x	x	x
FR26.	The SV and TV should support DCC functionalities to manage network load, if ITS-G5 is used	x	x	x	x	x	x	x

7.5 Management & security

FR27.	The SV should block the pseudonym change as long as the use case is not terminated			x	x			x

8 Operational requirements

8.1 Application layer

OR1.	The maximum deacceleration value of the vehicle may be dynamically set according to driving environment and vehicle type, vehicle load, etc. This value should not be lower than the value used by the collision avoidance function	X	x	x	x	x	x	x
OR2.	The SV and TV should be longitudinally in line with each other i.e. their lateral offset should be equal or lower than 2 m	x	x	x	x	x	x	x
OR3.	Driver should be informed on the current CACC on/off, standby and active state transition	x	x	x	x	x	x	x
OR4.	Driver may be informed of current Δt_{target} value		x	x	x	x	x	x
OR5.	Driver may be informed of nearby CACC string			x	x			
OR6.	In case of unknown trailer length, Δt_{target} should include safety margin to cover the trailer length	x	x	x	x	x	x	x

8.2 Facilities layer

Recommended requirements, numbers are subjected to change in the future after validation.

OR7.	CACC should enable lane level positioning e.g. the position accuracy should be equal or less than 2 m at lateral accuracy (difficult to achieve for longitudinal accuracy)	x	x	x	x	x	x	x
OR8.	Time offset between data in the CAM high frequency container with regards to time stamp should not exceed 20 ms	x	x	x	x	x	x	x
OR9.	Time stamp accuracy should be less than 1 ms	x	x	x	x	x	x	x
OR10.	The position and time information in CAM should be updated at minimum of 30 Hz (for option 2) See note 2	x	x	x	x	x	x	x
OR11.	Predicted path should cover the distance covered by at least 2 s	x	x	x	x	x	x	x
OR12.	As long as CACC remains activated, the ITS Station ID should be blocked	x	x	x	x	x	x	x
OR13.	CAM should provide path history of at least length of 2 s	x	x	x	x		x	x
NOTE 1: Set to maximum target time gap. NOTE 2: Maximum CAM transmission rate is as defined in clause 9.1.1.								

8.3 Networking & Transport layer

NA

8.4 Access layer

OR14.	SCH0 should be used for CACC data exchange, if ITS- G5 is used	x	x	x	x	x	x	x

9 Standards recommendations

9.1 Facilities layer

9.1.1 Options for CACC data inclusion in facilities layer PDU

The present clause defines data content to be exchanged between ITS-Ss to support CACC use cases as defined in the clause 5. The DEs and DFs should be included in facilities layer PDU (Protocol Data Unit) using one of following options:

- DEs and DFs are added in CAM as plain content. In this case, the DEs and DFs included in CAM will use the security profile for CAM, as specified in ETSI TS 103 097 [i.15]. In case DEs and DFs are not compliant to the GDPR and security policy specified in ETSI TS 102 894-2 [i.13] or in C-ITS security as defined in [i.14], those DEs and DFs should not be included in CAM as plain content.

- DEs and DFs are added in CAM as additional container. In this case, a new security profile should be defined. For example, the additional container may be encrypted if it contains data with privacy concern.

NOTE 1: Further analysis is needed to support nesting of security data structures within PDUs.

- DEs and DFs are used to construct a new facilities layer PDU or application messages. In this case, a new security profile should be defined for this message.

The list of the DE and DFs to support CACC use cases should be as defined in annex A of the present document.

NOTE 2: The data exchange needs may vary depending on the control logic being used. The present document includes the needs from stakeholders such as from R&D project [i.16].

NOTE 3: Other control logics and corresponding data exchange needs are defined in ISO/DIS/20035 [i.12].

At the reception of PDUs or messages containing CACC data, the receiving ITS-S processes the messages. The CACC application use the CACC data with data of received CAMs and DENMs to identify the TV and calculate the time gap with TV.

9.1.2 CA basic service

9.1.2.1 Introduction

This clause defines standards recommendations for the extensions of the CA basic service as specified in ETSI EN 302 637-2 [i.6].

By default, it is recommended that the ETSI EN 302 637-2 [i.6] requirements should remain, unless specified otherwise in the present clause.

9.1.2.2 Triggering conditions

For CACC application, the CA basic service should be used. The following triggering conditions for vehicle ITS-S CAM generation are used.

OPTION 1: When the CACC is engaged, or when the corresponding bit of the caccEngaged value in a received CAM is set to 1, the *T_GenCam* should be set to 100ms. The low frequency container is transmitted every 5 messages.

OPTION 2: When the CACC is engaged, the *T_GenCam* should be set according to the target distance value *Δttarget*, as illustrated in Figure 13. The low frequency container is transmitted every 5 messages. The following parameter setting may be used:

- T_GenCamMin = 30 ms
- T_GenCamMax = 100 ms
- ΔttargetMin = 0,5 s
- ΔttargetMax = 2 s

NOTE: Option 2 would probably require double transceiver because 30Hz CAM transmission would probably result in a channel overload.

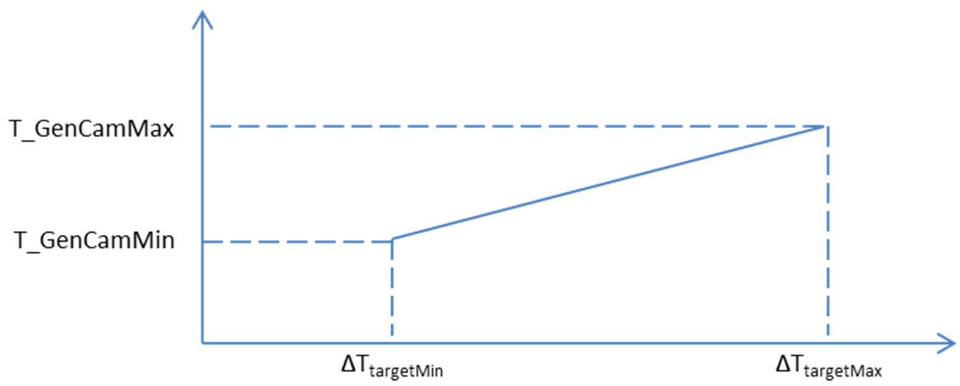


Figure 13: T_GenCam value setting rule for CACC

When CACC is in engaged mode, a CAM should include DE and DF as specified in clause A.1 and should not include *specialVehicleContainer*.

For road side ITS-S CAM, the triggering conditions options are:

OPTION 1: Periodic transmission with fixed rate (e.g. 1 Hz).

OPTION 2: Periodic transmission triggered by Road side ITS-S application, e.g. by receiving vehicle ITS-S CAM.

9.1.2.3 Message content extension

As introduced in clause 9.1.1, CAM may be extended with additional DE, DFs as specified in annex A of the present document.

9.1.2.4 Dissemination requirements

Idem to the CA basic service as defined in ETSI EN 302 637-2 [i.6] (one hop broadcast).

9.1.2.5 Dissemination protocol

Idem to the CA basic service as defined in ETSI EN 302 637-2 [i.6].

9.1.2.6 Security requirements

9.1.2.6.1 ITS AID management

ITS AID should be set as specified in ETSI EN 302 637-2 [i.6].

9.1.2.6.2 SSP

The following SSP definition should be used for CAM. One bit is used to indicate whether or not road side ITS-S is authorized to provide road side CACC service as introduced in UC004 (see clause 5.4).

Octet Position	Bit Position	Permission Items	Bit Value
1	0 (80h) (MSBit)	CenDsrcTollingZone/ ProtectedCommunicationZonesRSU	0: certificate not allowed to sign 1: certificate allowed to sign
1	1 (40h)	publicTransport / publicTransportContainer	0: certificate not allowed to sign 1: certificate allowed to sign
1	2 (20h)	specialTransport / specialTransportContainer	0: certificate not allowed to sign 1: certificate allowed to sign
1	3 (10h)	dangerousGoods / dangerousGoodsContainer	0: certificate not allowed to sign 1: certificate allowed to sign
1	4 (08h)	roadwork / roadWorksContainerBasic	0: certificate not allowed to sign 1: certificate allowed to sign
1	5 (04h)	rescue / rescueContainer	0: certificate not allowed to sign 1: certificate allowed to sign
1	6 (02h)	emergency / emergencyContainer	0: certificate not allowed to sign 1: certificate allowed to sign
1	7 (01h) (LSBit)	safetyCar / safetyCarContainer	0: certificate not allowed to sign 1: certificate allowed to sign
2	0 (80h) (MSBit)	closedLanes / RoadworksContainerBasic	0: certificate not allowed to sign 1: certificate allowed to sign
2	1 (40h)	requestForRightOfWay / EmergencyContainer: EmergencyPriority	0: certificate not allowed to sign 1: certificate allowed to sign
2	2 (20h)	requestForFreeCrossingAtATrafficLight / EmergencyContainer: EmergencyPriority	0: certificate not allowed to sign 1: certificate allowed to sign
2	3 (10h)	noPassing / SafetyCarContainer: TrafficRule	0: certificate not allowed to sign 1: certificate allowed to sign
2	4 (08h)	noPassingForTrucks / SafetyCarContainer: TrafficRule	0: certificate not allowed to sign 1: certificate allowed to sign
2	5 (04h)	speedLimit / SafetyCarContainer	0: certificate not allowed to sign 1: certificate allowed to sign
2	**6 (02h)**	**roadSideCacc/roadSideCaccContainer**	**0: certificate not allowed to sign** **1: certificate allowed to sign**
2	7 (01h) (LSBit)	reserved for future usage	not used, set to 0.

9.2 Networking & Transport layer

No additional requirements are defined for Networking & Transport layer.

9.3 Access layer

9.3.1 Channel usage

The CACC data should be transmitted over SCH0, if ITS G5 is used.

9.3.2 Over-the-air update

The extension of CAM and DENM as proposed by the present document breaks backward compatibility. The required SW update may be realized via Over-the-air update functionalities.

9.4 Management & security

9.4.1 Communication profile and SAM

In case the road side ITS-S provides road side CACC service for CACC string, the CACC string forming and dissolution information is included in CAM transmitted from road side ITS-S. It is assumed that the road side ITS-S transmit CAM over a "always on" communication channel. At the reception of this CAM, a vehicle ITS-S does not need to access to other communication channel or access technologies to receive CACC service related information, therefore, SAM is not needed.

9.4.2 Security and privacy

A security and privacy analysis should be realized for recommendations of the present document and should provide guidance for the options below, taking into account the European GDPR (EU General Data Protection Regulation) regulation:

- If DE or DF as defined in the present document are added in CAM as plain content, CAM by vehicle ITS-S and road side ITS-S should be signed with a valid certificate containing a valid SSP as defined in clause 9.1.2.6.2.
- If DE or DF as defined in the present document are added in CAM as container, such container may be encrypted and attached to the CAM for transmission.
- If DE or DF as defined in the present document are transmitted as standalone messages, such messages may be encrypted.

Annex A:
Recommendations on CACC DEs and DFs

A.1 DEs and DFs to support CACC use cases

The present clause defines additional DEs and DFs to be exchanged between ITS-Ss to support CACC use cases. It also defines recommendations on modifications on existing DEs and DFs as specified in ETSI TS 102 894-2 [i.13].

```
AccelerationControl ::= BIT STRING {  brakePedalEngaged (0),  gasPedalEngaged (1),  emergencyBrakeEngaged (2),
collisionWarningEngaged (3),  accEngaged (4),  cruiseControlEngaged (5),  speedLimiterEngaged (6) ,
caccEnganged(7)} (SIZE(14))

TimeToPrecedingVehicle DeltaTimeStamp,

AutomatedVehicleContainerLowFrequency ::= SEQUENCE {

automatedControl AutomatedControl,

targetSpeed SpeedValue,

targetLongitudinalAcceleration LongitudinalAccelerationValue,

brakingCapacity LongitudinalAccelerationValue,

targetTimeToPrecedingVehicle DeltaTimeStamp OPTIONAL,

targetTimeToFollowingVehicle DeltaTimeStamp OPTIONAL,

pathPrediction PathPrediction OPTIONAL,

groupID GroupID OPTIONAL,

groupSpeed SpeedValue OPTIONAL,

limitedLength RelevanceDistance OPTIONAL,

stringLeadVehiclePosition ReferencePosition,

limitedLengthInNumber INTEGER(0..255) OPTIONAL,

orderInString INTEGER(0..255),

leadVehicle stationID,

…

}

RoadSideSupportedAutomatedDriving::= SEQUENCE {

recommendedTargetTimeGap DeltaTimeStamp OPTIONAL,

startingPosition ReferencePosition OPTIONAL,

caccLanePosition LanePosition OPTIONAL,

recommendedSpeed SpeedValue OPTIONAL,

limitedLength Distance OPTIONAL,

stringLeadVehiclePosition ReferencePosition,

limitedLengthInNumber INTEGER(0..255) OPTIONAL,
```

```
recommendedVehicleType StationType OPTIONAL
}


AutomatedControl ::= BIT STRING {
automaticLaneChangeEngaged (0),
stringEngaged (1),
platooningEngaged (2),
laneKeepAssistEngaged (3),
caccEngaged (4),
…
} (SIZE (15))
PathPrediction ::= SEQUENCE SIZE (1..23) OF PredictedPathPoint
PredictedPathPoint ::= SEQUENCE {
predictedPathDeltaTime PredictedPathDeltaTime,
predictedPathDeltaPosition DeltaReferencePosition,
predictedPathDeltaPositionConfidence DeltaPositionConfidenceEllipse,
predictedPathDeltaSpeed DeltaSpeed OPTIONAL,
predictedPathDeltaLongitudinalAcceleration DeltaAcceleration OPTIONAL,
predictedPathDeltaLateralAcceleration DeltaAcceleration OPTIONAL
}
PredictedPathDeltaTime ::= INTEGER {tenMilliSecondsInFuture(1)} (1..1024, ...)
DeltaPositionConfidenceEllipse ::= SEQUENCE {
deltaSemiMajorConfidence DeltaSemiAxisLength,
deltaSemiMinorConfidence DeltaSemiAxisLength,
deltaSemiMajorOrientation DeltaHeadingValue
}
DeltaSemiAxisLength ::= INTEGER { outOfMinimumRange(-512), plusOneCentimeter(1),
outOfMaximumRange(1534), unavailable(4095) } (-512..1534 | 4095)
DeltaHeadingValue ::= INTEGER{ plusDotOneDegrees(1), unavailable(3600) } (-511..511 | 3600)
DeltaSpeed ::= SEQUENCE {
deltaSpeedValue DeltaSpeedValue,
deltaSpeedConfidence DeltaSpeedConfidence
}
DeltaSpeedValue ::= INTEGER { minusDotOneMeterPerSec(-1), plusDotOneMeterPerSec(1), outOfMinimumRange(-
255), outOfMaximumRange(255), unavailable(16383) } (-255..255 | 16383)
```

```
DeltaSpeedConfidence ::= INTEGER { outOfMinimumRange(-63), minusDotOneMeterPerSec(-1),
plusDotOneMeterPerSec(1), outOfMaximumRange(63), unavailable(127) } (-63..63 | 127)
DeltaAcceleration ::= SEQUENCE {
deltaAccelerationValue DeltaAccelerationValue,
deltaAccelerationConfidence DeltaAccelerationConfidence
}
DeltaAccelerationValue ::= INTEGER { minusDotOneMeterPerSecSquared(-1),
plusDotOneMeterPerSecSquared(1), unavailable(161) }(-63..63 | 161)
DeltaAccelerationConfidence ::= INTEGER { minusDotOneMeterPerSeqSquared(-1),
plusDotOneMeterPerSecSquared(1), unavailable(102) }(-63..63 | 102)
GroupID ::= INTEGER (0..255)
```

A.2 DE and DF data setting rules

A.2.1 accelerationControl

Description	This DE indicate if CACC application is engaged or not.
Data setting and presentation requirements	This DE as defined in ETSI TS 102 894-2 [i.13] should be revised as specified in annex A. When CACC is engaged, the corresponding bit should be set to 1. The definition of other bits should be as defined in ETSI TS 102 894-2 [i.13].

A.2.2 timeToPrecedingVehicle

Description	The measured time gap between ego vehicle (CACC engaged vehicle) and preceding vehicle.
Data setting and presentation requirements	This DE should be presented as DE GenerationDeltaTime as specified in ETSI EN 302 637-2 [i.6].

A.2.3 automatedVehicleContainerLowFrequency

Description	A DF transmitted by vehicle ITS-S when automated driving function such as CACC is engaged.
Data setting and presentation requirements	This DF should be presented as specified in clause A.1. This DF should be transmitted at least at the same transmission rate as CAM *basicVehicleContainerLowFrequency*.

A.2.4 roadSideSupportedAutomatedDriving

Description	The high frequency container transmitted by a road side ITS-S to support UC004 and other road side assisted automatic driving. This container may be included in CAM *rsuContainerHighFrequency*, or in a standalone CACC message.
Data setting and presentation requirements	This DF should be presented as specified in annex A. When CACC is engaged, this DF should include the DF *roadSideCaccContainer.*

A.2.5 automatedConrtrol

Description	The DE provides the automatedControl system being engaged by the vehicle. For example, when a lane keeping assistance system is engaged, the corresponding bit should be set to 1.
Data setting and presentation requirements	This DE should be presented as specified in clause A.1.

A.2.6 targetSpeed

Description	Target speed set by the CACC application.
Data setting and presentation requirements	This DE should be presented as *SpeedValue* as specified in ETSI TS 102 894-2 [i.13].

A.2.7 targetLongitudinalAcceleration

Description	Target longitudinal acceleration set by the CACC application.
Data setting and presentation requirements	This DE should be presented as DF LongitudinalAccelerationValue as specified in ETSI TS 102 894-2 [i.13].

A.2.8 brakingCapacity

Description	Maximum braking capacity of the vehicle.
Data setting and presentation requirements	This DE should be presented as DE LongitudinalAccelerationValue as specified in ETSI TS 102 894-2 [i.13].

A.2.9 targetTimeToPrecedingVehicle

Description	Target time gap set by the CACC application to the preceding vehicle.
Data setting and presentation requirements	This DE should be presented as DE GenerationDeltaTime as specified in ETSI EN 302 637-2 [i.6].

A.2.10 targetTimeToFollowingVehicle

Description	Target time gap set by the CACC application to the following vehicle.
Data setting and presentation requirements	This DE should be presented as DE GenerationDeltaTime as specified in ETSI EN 302 637-2 [i.6].

A.2.11 pathPrediction

Description	Predicted path of the vehicle.
Data setting and presentation requirements	This DF should be presented as PathHistory as specified in ETSI TS 102 894-2 [i.13].

A.2.12 groupID

Description	ID the CACC string, as randomly generated by the vehicle at the CACC engagement starts. If vehicle ITS-S receives a CAM from surrounding vehicle ITS-S which includes already a group ID, and the vehicle ITS-S decides to join the CACC string, it should set this DE as the same value as CACC string. Otherwise, a new value should be generated.
Data setting and presentation requirements	This DE should be presented as specified in clause A.1.

A.2.13 groupSpeed

Description	Measured speed of the CACC string.
Data setting and presentation requirements	This DE should be presented as DE SpeedValue as specified in ETSI TS 102 894-2 [i.13].

A.2.14 limitedLength

Description	Limited total length of the CACC string, if known.
Data setting and presentation requirements	This DE should be presented as RelevanceDistance DE as specified in ETSI TS 102 894-2 [i.13].

A.2.15 stringLeadVehiclePosition

Description	Last known position of the string lead vehicle.
Data setting and presentation requirements	This DF should be presented as ReferencePosition DF as specified in ETSI TS 102 894-2 [i.13].

A.2.16 limitedLengthInNumber

Description	Limited length of CACC string in number of vehicle, if know.
Data setting and presentation requirements	This DE should be presented as in annex A.

A.2.17 orderInString

Description	Position of transmitting vehicle ITS-S in CACC string, counted from lead vehicle.
Data setting and presentation requirements	This DE should be presented as in clause A.1.

A.2.18 leadVehicle

Description	Station ID of the CACC string lead vehicle.
Data setting and presentation requirements	This DE should be presented as DE StationID as specified in ETSI TS 102 894-2 [i.13].

A.2.19 roadSideCaccContainer

Description	CACC control information transmitted from road side ITS-S.
Data setting and presentation requirements	This DF should be presented as specified in clause A.1.

A.2.20 recommendedTargetTimeGap

Description	Recommended target time gap for vehicles accepting road side CACC service.
Data setting and presentation requirements	This DE should be set to DeltaTimeStamp as defined in ETSI TS 102 894-2 [i.13].

A.2.21 startingPosition

Description	Position starting from which the road side CACC service is available.
Data setting and presentation requirements	This DF should be presented as DF ReferencePosition as specified in ETSI TS 102 894-2 [i.13].

A.2.22 caccLanePosition

Description	Lane at which the road side CACC service is available.
Data setting and presentation requirements	This DE should be presented as DE LanePosition as specified in ETSI TS 102 894-2 [i.13].

A.2.23 recommendedSpeed

Description	Recommended speed limit for vehicles using the road side CACC service.
Data setting and presentation requirements	This DE should be presented as DE SpeedLimit as specified in ETSI TS 102 894-2 [i.13].

A.2.24 recommendedVehicleType

Description	Types of vehicles which may use the road side CACC service.
Data setting and presentation requirements	This DE should be presented as DE StationType as specified in ETSI TS 102 894-2 [i.13].

Annex B: Application state machine transition

An example CACC application state machine diagram is described in Figure B.1 with the following machine states:

- CACC on: this state is triggered when the CACC is switched on, either manually by driver or automatically;
- ACC on: this state is triggered when the CACC is switched on, but no message is received from any vehicle in the surrounding area;
- ACC engaged: this state is switched from ACC on mode, and it is triggered when a TV is identified using in vehicle sensor information only;
- CC on: in this state, the CC is switched on. It may be triggered from ACC engaged state when no TV is identified;
- CACC active: when the CACC is set to CACC_on and at least one valid message is received from vehicles in the surrounding area;
- CACC engaged: when CACC is set to CACC idle, then a TV is identified and CACC parameters are set, including target time gap;
- CACC/ACC assisted: when control command is determined and sent to vehicle actuators or to other in vehicle assistance system. The system may be switched to CACC idle mode when TV is lost;
- CACC stand by: the CACC is at CACC on mode but no valid message is yet received;
- CACC off: the CACC is switched to off mode when the predefined off conditions are met. The off conditions definitions may be at the discretion of implementers.

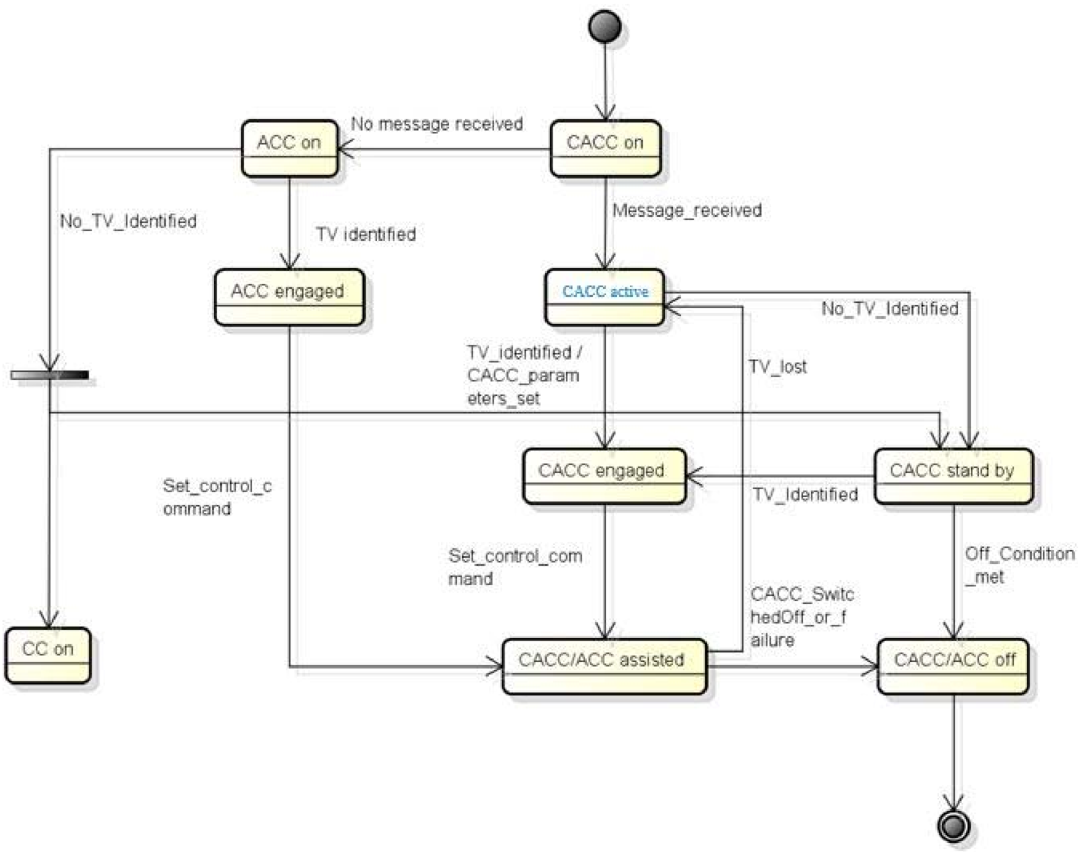


Figure B.1: CACC application state machine diagram

Annex C: Bibliography

- ISO/TS 21219-1:2016: "Intelligent transport systems -- Traffic and travel information (TTI) via transport protocol experts group, generation 2 (TPEG2) -- Part 1: Introduction, numbering and versions (TPEG2-INV)".

History

Document history		
V2.1.1	June 2019	Publication