Automotive Association

System Enablers and Best Practices for Next-Gen Cooperative Use Cases

5GAA Automotive Association
Technical Report

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Contents

Foreword

This Technical Report has been produced by 5GAA.

The contents of the present document are subject to continuing work within the Working Groups (WG) and may change following formal WG approval. Should the WG modify the contents of the present document, it will be re-released by the WG with an identifying change of the consistent numbering that all WG meeting documents and files should follow (according to 5GAA Rules of Procedure):

x-nnzzzz

(1) This numbering system has six logical elements:

(a) x: a single letter corresponding to the working group:

where x =

T (Use cases and Technical Requirements)

A (System Architecture and Solution Development)

P (Evaluation, Testbed and Pilots)

S (Standards and Spectrum)

B (Business Models and Go-To-Market Strategies)

(b) nn: two digits to indicate the year. i.e. ,17,18 19, etc

(c) zzzz: unique number of the document

(2) No provision is made for the use of revision numbers. Documents which are a revision of a previous version should indicate the document number of that previous version

(3) The file name of documents shall be the document number. For example, document S-160357 will be contained in file S-160357.doc

Introduction

In the connected future of transportation, there will be an ever-growing set of cooperative Use Cases that need to be enabled in a standardised fashion. As the implementation of these Day 2+ Use Cases is different from the so far existing Use Cases, new, different information exchanges than the currently existing beacon message structures will be required. To determine similarities and common mechanisms for this group of Use Cases, a definition was undertaken to provide a guideline in the field of such new Use Cases. The term Complex Interaction was selected to describe Use Cases that require an exchange of sequential information with a minimum of three consecutive exchanges. If unique protocols and messages are to be developed for each individual Use Case, the amount of technical complexity would soon become unmanageable. Thus, it is vital to have a scalable framework for these Complex Interactions that covers common technical enablers. Since so far no general requirements, descriptions and repeated behaviours have been identified for such Complex Interactions, the work introduced here presents an evaluation and representation of requirements which have been determined and developed during the analysis. It further demonstrates the results gathered, reviews the so-called Complex Interactions and provides findings of required mechanisms with proposed solutions with a way to implement and enable new messages and exchanges. Additionally, the findings were established by acknowledging the technical enablers provided by the 3GPP PC5-[x] functionalities and propose additions to further enhance the Complex Interaction Framework.

1 Scope

The present document contains the findings developed and evaluated within the 5GAA Cross-Working-Group Work Items 'Accelerate definition of C-V2X based on 5G New Radio or future LTE enhancements' [XW1-190000] and 'Defining Complex V2X Interactions for 5GNR' [T-200073] presented along with the used methodology.
The results and conclusions of this report are intended to serve as input for the work of other WGs and WIs within the 5GAA, as well as input and feedback to standardisation activities such as are undertaken in 3GPP, SAE or ETSI.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

[1] 3GPP TS 23.287: "Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services"

[2] 3GPP TS 38.300: 'NR; NR and NG-RAN Overall description; Stage-2'

[3] C-V2X Use Cases and Service Level Requirements Volume I – 5G Automotive Association (5gaa.org)

[4] C-V2X Use Cases and Service Level Requirements Volume II – 5G Automotive Association (5gaa.org)

[T-180152] Group Start
[T-190128] Coordinated Cooperative Driving Manoeuvre
[T-190132] Curb-Side Management
[T-190133] Interactive VRU Crossing
[T-190136] Vehicle Decision Assist
[T-190134] Cooperative Lateral Parking
[T-200023] Cooperative Traffic Gap
[T-190156] Bus Lane Sharing
[T-190155] Bus Lane Sharing
[T-190032] Cooperative Lane Merge

3 Definitions and Abbreviations

3.1 Definitions

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

Addressability: *The capability of a device to addressing devices, or the capability of a device to be addressed by another*

Addressing: *Using a communication address such as an ID to communicate with capable devices*

Complex Interaction*: A Use Case requiring a minimum of three messages or information exchanges to be executed consecutively.*

Data Element: *A component of an application layer message in a defined data format representing a specific type of information.*

Functional Mechanism*: A mechanism that can be used to execute a part of a Complex Interaction Use Case and provides a solution to a problem or requirement. Multiple Functional Mechanisms can be assembled to provide an implementation of a Use Case. A Functional Mechanism can provide a solution by different technical means.*

Initiation*: The moment the critical process of the Use Case starts. This can for example be the beginning of a manoeuvre.*

Message: *An application layer message transporting information required by the applications between different V2X-enabled devices. Messages of the facilities layer are described in ETSI Basic Services.*

Participant*: A user or device directly involved in the execution of a Use Case. These can be road vehicles or VRUs, but also Traffic Lights or RSUs.*

Safety Critical: *Something is safety critical when physical danger is imminent. This can be in the form of a crash or collision between participants.*

3.2 Abbreviations

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

5G	Fifth Generation, Corresponds to Rel.15/16 for the 3GPP Standard Suite NR
ACK	Acknowledgement
AL-FEC	Application Layer Forward Error Correction
ARQ	Automatic Repeat reQuest
AVP	Automated Valet Parking
BSM	Basic Safety Message, Standardised Message in the SAE Standard Suite
CAM	Cooperative Awareness Message, Standardised Message in the ETSI ITS G5 Standard Suite
C-ITS	Connected Intelligent Transport Systems
FEC	Forward Error Correction
GNSS	Geo-Navigation Satellite System
HARQ	Hybrid ARQ
HV	Host Vehicle
LDM	Local Dynamic Map
MIMO	Multiple-Input Multiple-Output
NACK	Negative-Acknowledgement
PC5	Device-to-Device Interface Sidelink at the Physical Layer
PDU	Protocol Data Unit
PHY	Physical Layer: Corresponds to the Lowest Layer of the OSI Structure
RSU	Road Side Unit
RV	Remote Vehicle
SLR	Service-Level Requirement
UE	User Equipment
V2X	Vehicle-to-Everything
V2X AS	V2X Application Server
VRU	Vulnerable Road User

4 Methodology

4.1 General Considerations

The methodology selected for the evaluation is represented by the following four steps:

1. First, a selection of Use Cases presented in [3] and [4] that match the definition of Complex Interaction was made. A brief introduction of the selected Use Cases including description of their connection to ‘complexity’ is presented in Chapter 6. These Use Cases were selected to serve as an evaluation basis for future and existing Use Case requirements.
2. In the second step, differences and commonalities of these Use Cases were reviewed and are presented and briefly explained in Chapter 7.
3. Based on Step 2, the identified common overarching requirements are presented in Chapter 7 and possible solutions to the requirements are briefly introduced.

4. Finally, existing Key Enabler Technologies and their connection to the investigated Use Cases were analysed and are presented in Chapter 9.

The Use Cases considered in this report are:

- Group Start [T-180152]
- Coordinated Cooperative Driving Manoeuvre [T-190128]
- Cooperative Curb-Side Management [T-190132]
- Interactive VRU Crossing [T-190133]
- Vehicle Decision Assist [T-190136]
- Cooperative Lateral Parking [T-190134]
- Cooperative Traffic Gap [T-200023]
- Bus Lane Sharing [T-190155] & [T-190156]
- Cooperative Lane Merge [T-190032]

On top of the findings detailed in the steps above, three Use Cases were evaluated in more depth during Step 3. The findings of this detailed evalutation resulted in an example implementation for each of the three Use Cases:

- Interactive VRU Crossing
- Coordinated Cooperative Driving Manoeuvre to implement a Lane Merge
- Group Start

This includes message exchanges fulfilling the requirements of the Use Case and SLRs. The main aspects considered for the detailed evaluation were the:

- Group management principles and behaviours
- Communication needs of the Use Case
- Information flow in the right order and required number of exchanges
- Use Case participants
- Use Case locations
- Execution timeframe of the Use Cases

Furthermore, the detailed inspection of the three Use Case has effectively applied the general mechanisms and made use of one of the possible solutions for the required mechanisms at the different Use Case steps. Key Enabler Technologies, such as Addressing, were equally considered for the detailed evaluation.

The report will conclude with a brief summary and outlook on future activities required, deduced by the common needs of Complex Interaction Use Cases.

4.2 Assumptions for Evaluation

Multiple assumptions were made for the evaluation of the Complex Interactions. Since the Use Cases vary considerably in their functionality from one another, some assumptions specifically relate to these requirements.

Assumptions related to **implementation**:

- From the different possible implementations of each Use Case, only one implementation was used for analysis. The gained insights may not cover the different possible implementations of one Use Case.
- The exchanges considered between vehicles are exclusively via Sidelink PC5 when not explicitly described otherwise. It serves as an evaluation of the direct link V2X functionalities and does not imply that this is the most effective implementation.
- The participants all support the functions and are equipped with hardware and software required for the Use Case.
- The Use Case is executed via explicit information exchanges between the participants. This can be implemented in other ways, but is chosen here to determine the extent of the implementation range and to understand the possible interactions between vehicles.
- The vehicles have knowledge of the road topology and its surroundings via different input sources, such as sensors, map providers, and GNSS information or functions including a Local Dynamic Map generated within the vehicle.
- The positioning accuracy required from the vehicles is taken from the Use Case descriptions (the method for acquiring the positioning accuracy is out-of-scope). The assumption is that the required accuracy is achieved by all Use Case participants.
- Cyclic beacon messages of the type CAM or BSM are implemented by all Use Case participants. The information contained can be used for the execution of Complex Interactions.
- The presence of different participant types such as VRUs, RSUs and regular vehicles are present and available on location, where the Use Cases take place.
- Acknowledgements on the Physical and Application Layer are possible (such as HARQ PHY Rel.16).
- Lower-layer mechanisms allowing Addressing individual participants, groups or all traffic participants are enabled, and only the affected participants can actively be involved in the Use Case.
- Other messages and data elements than the ones already available to implement the Use Cases are applied, however the use of already defined data elements is favoured at all times.

Assumptions related to **designing the system**:

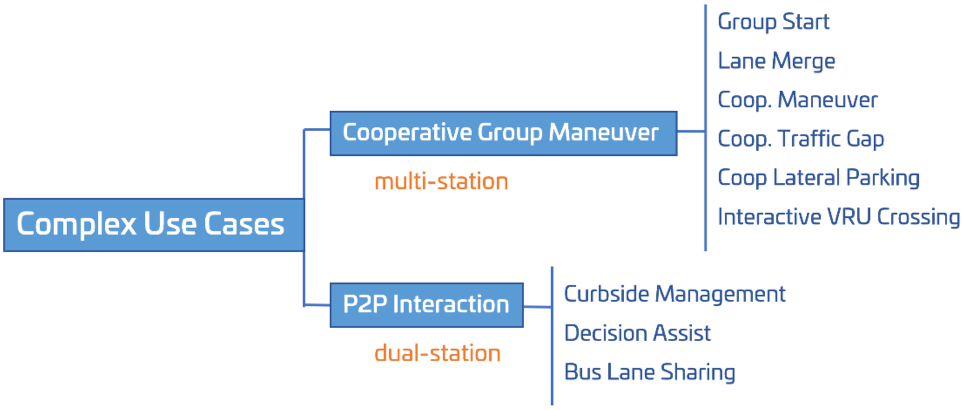
- Although participation in a Use Case is beneficial for all, any vehicle may decide not to participate. Consequently, it cannot be assumed that a Complex Interaction Use Case will always take place, in particular when vehicles essential to the execution decide not to participate.
- Vehicles may stop participating in a Complex Interaction Use Case at any point in time. It is assumed that enough safety distance is guaranteed throughout any Use Case such that a participant dropping out does not cause issues. This is especially important in accommodating emergency vehicles.
- Wireless communication is error prone. For safety-critical messages, the sender needs to ensure the information is received. The sender monitors the process of message acknowledgement on the application layer and may resend a message, call off the Use Case execution or take other precautions in the event of failure.
- Scenarios need to be considered in unpredictable circumstances during the Complex Interactions exchange. This ensures the initiation of the Use Case regardless of possible situational shortfalls.
- If an unequipped/non-communicating/non-interoperable technology vehicle is present in the Use Case environment, this vehicle is not considered a ‘participant’ in the initiation and the Use Case needs to be executed without this vehicle’s involvement. Connected vehicles capable of sending CAMs/BSMs but not responding or interacting with more recent messages are not considered as Use case participants either. Even though they may be capable of being notified about such Complex Interaction, they are not meant to participate as such. The design of the Use Case needs to consider non-V2X vehicles in the treatment of safe Use Case execution, but not for the communication taking place within the Use Case per se.
- The Use Case needs to be implementable regardless of the presence of unequipped/non-communicating/non-interoperable technology vehicles and participants.
- Negotiation is considered a requirement to ensure the execution of the Use Cases, even though the negotiated parameters might not be the optimised way forward for the individual participants. Overall, the execution is designed to be the most effective and achievable, considering the situation-specific circumstances, with regards to safety, speed, control, and comfort of the overall execution.

There are multiple degrees of cooperation between vehicles when implementing a Use Case depending on the approach to implementation chosen during its design. Therefore, it is very possible that a Use Case can be implemented with varying factors and considerations to achieve the same movement or information exchange. However, the more cooperative the Use Case, the more information exchanges, measurements and calculations must be undertaken, such as trajectory measurements. This, in turn, means the degree of cooperativeness that can be implemented directly correlates with the available hardware and software resources of the participants.

5 Introduction and Selection of Use Cases

From the technical releases presented in [3] and [4], an extensive list of Use Cases was examined and all of those requiring a minimum of three consecutive information exchanges were selected.

5.1 Use Case Groupings



Generally, the investigated Use Cases can be placed in two groups:

- Group Manoeuvres
- One-to-One Interactions.

The exchanges all correspond to Complex Interactions; however, the quantity of participants is different. The One-to-One Use Cases only require information exchanges between two participants, which are addressed directly, while in the Group Manoeuvres, more than two/ participants need to be addressed in at least one stage of the implementation. It should be considered that this grouping corresponds to the investigated implementations only.

5.1.1 Group Manoeuvre Use Cases

- A group of vehicles (>2) aim for a cooperative manoeuvre
- The manoeuvre is requested/initiated by one (can be requested or advertised)
- The group members of the manoeuvre need to be managed
- The manoeuvre is agreed/negotiated between group members
- Group communication is bi-directional
- Group communication needs to be reliable
- Works along the 3 Phases: 1. Group Selection and Decision, 2. Manoeuvre Execution and Group Maintenance, 3. Finalisation

5.1.2 One-to-One Interaction Use Cases

- Two traffic participants agree on a certain action
- The action is requested/initiated by one (can be requested or advertised)
- The communication is bi-directional
- The communication does not necessarily have to be reliable

5.2 Use Cases with Complex Interactions

From the Use Cases defined within 5GAA, the following nine were selected. Here they will be briefly introduced, and their complexity will be categorised along the following lines or labels:

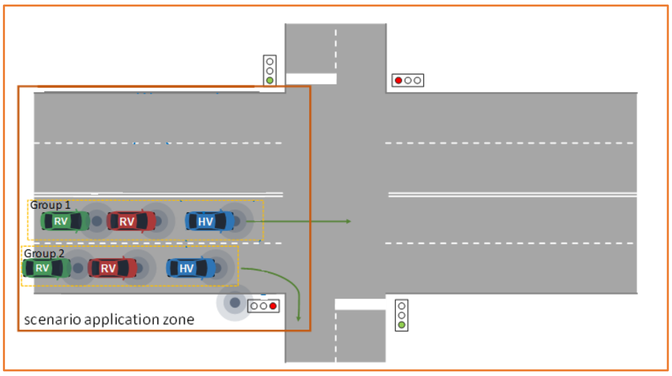
- **Group-Management:** To plan and implement certain Use Cases, some form of communication between dedicated participants has to be set up and the parameters of the Use Cases have to be negotiated. Here, a type of management of a group is required.
- **Multi-Vehicle-Action:** The decision-making process is not carried out by a dedicated user but is instead distributed amongst the participants.

- **Action-Variety:** To implement the Use Case, the vehicle is required to execute different and multiple actions such as sending specific messages, executing different parameter selections and calculations, or executing different separate movements
- **Heterogenous-V2X-Capabilities:** To execute the Use Case, different types of V2X communication are required. This also includes the consideration of vehicles that do not have any V2X communication.

Note: One or more of these characteristic labels can be present within a Complex Interaction Use Case.

5.2.1 Group Start

Self-driving or semi-automated vehicles form a group to jointly start at a traffic light. The group only exists during the movement through the intersection when the traffic light turns green. After that, the group is automatically dissolved, no platoon is formed.

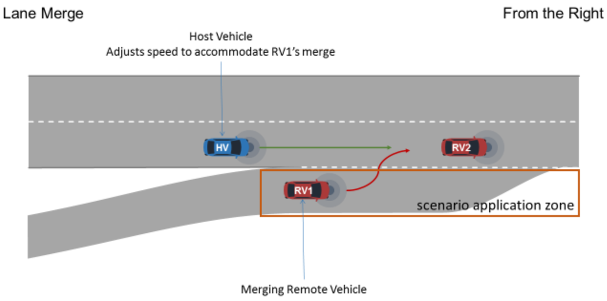


Group Start requires multiple exchanges and negotiations between actors, since coordination is required for the implementation. This is explained by the range of possible parameters and because participating vehicles display considerable differences in acceleration, weight and trajectory, which directly affects the way Group Start will be implemented at different intersections and in different lanes and travel directions.

Use Case complexity specifics: Group-Management, Multi-Vehicle-Action, Action-Variety, Heterogenous-V2X-Capabilities.

5.2.2 Coordinated Cooperative Driving Manoeuvre, Execution of Lane Merge

A Host Vehicle requests remote vehicles in a lane to accommodate its merging into the remote vehicle's traffic lane.

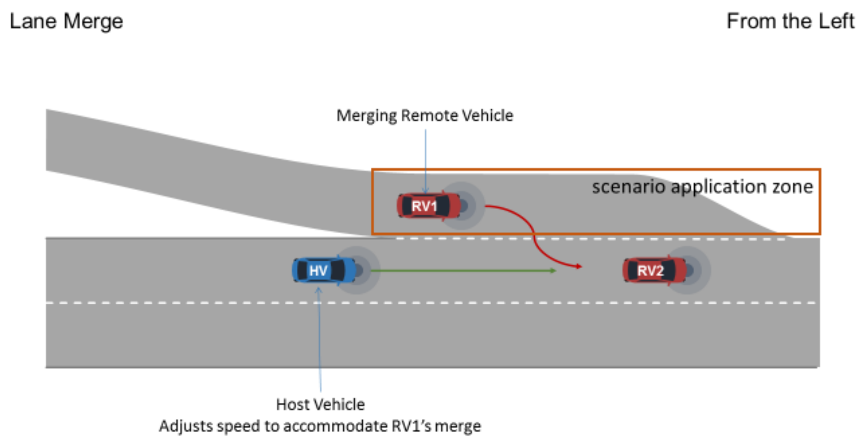


Lane Merging Mechanisms require the vehicles present in the lane to agree and accept the manoeuvre the merging vehicle is undertaking. This varies with acceptance, speed and braking capacities of the different participants and these crucial vehicle-capabilities have to be known to the enabler and merging vehicles, so achievable speeds and time frames can be realised. This requires several sequential exchanges to identify potential involved vehicles and subsequently communicate the possible parameter.

Use Case complexity specifics: Group-Management, Multi-Vehicle-Action, Action-Variety**,** Heterogenous-V2X-Capabilities

5.2.3 Cooperative Lane Merge/Cooperative Lane Change

Cooperative Lane Merge slightly differs in the approach of creating and initiating the merge of a vehicle in comparison to 5.1.2. Here, the vehicle in the lane detects a vehicle's need to merge into its lane and initiates and accommodates the manoeuvre.

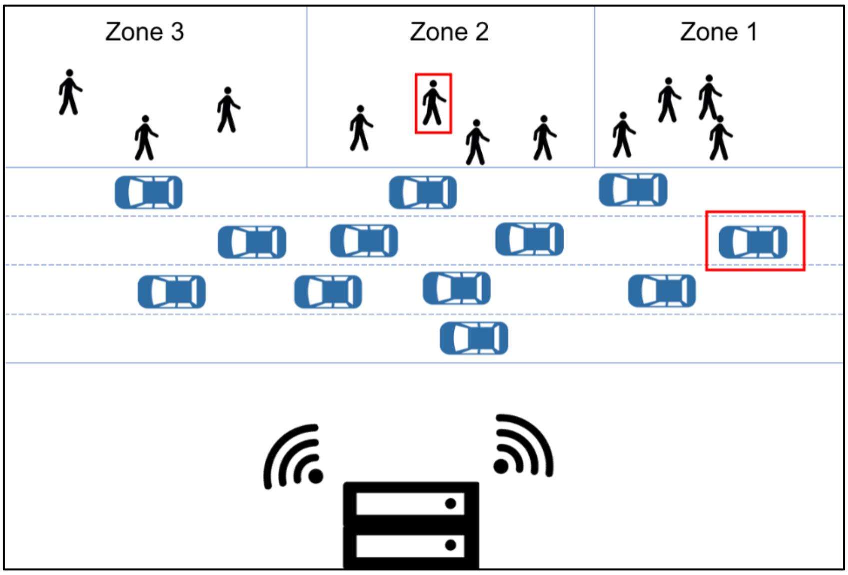


Similar to 5.1.2, Cooperative Lane Merge requires multiple parameters and conditions to be exchanged between participants before the merging can take place.

Use Case complexity specifics: Group-Management, Multi-Vehicle-Action, Action-Variety, Heterogenous-V2X-Capabilities.

5.2.4 Cooperative Curbside Management

A pedestrian and a vehicle are planning a pickup at a crowded curbside to improve the efficiency and safety of this densely populated area. The overall objective is to shorten and ease the pickup.



The management of the different arriving and departing vehicles adapting to their goal of dropping-off or picking-up one or multiple people requires the exchange of various data and in a completely unpredictable fashion. Here, the Managing Unit has to coordinate and accommodate parking spaces for vehicles but also locations for pedestrians, creating an exchange over multiple user types.

Use Case complexity specifics: Action-Variety, Heterogenous-V2X-Capabilities.

5.2.5 Interactive VRU Crossing

A Vulnerable Road User, such as a pedestrian or cyclist, signals his or her intention to cross a road and interacts with vehicles approaching the area to improve their safety and vehicle awareness. The affected vehicles form a temporary group in order to communicate with the VRU while he/she is crossing the street. When the VRU finishes crossing the street, the group is automatically dissolved.

By enabling the pedestrian to request/inform the vehicles of an intent, the vehicles can react and the exchange between VRU and vehicles becomes a negotiation of suitable conditions to ensure that all actors can successfully support the action safety.

Use Case complexity specifics: Group-Management, Multi-Vehicle-Action, Action-Variety**,** Heterogenous-V2X-Capabilities.

5.2.6 Vehicle Decision Assist

This feature helps a vehicle to decide whether it should overtake a stationary or slow vehicle it detects in front.

As the Use Case manifests assistance of one vehicle to facilitate the movement of another, coordination is required to identify which manoeuvre is planned but also if the manoeuvre can be satisfied and in which timeframe this is to take place.

Use Case complexity specifics: Multi-Vehicle-Action, Action-Variety.

5.2.7 Cooperative Lateral Parking

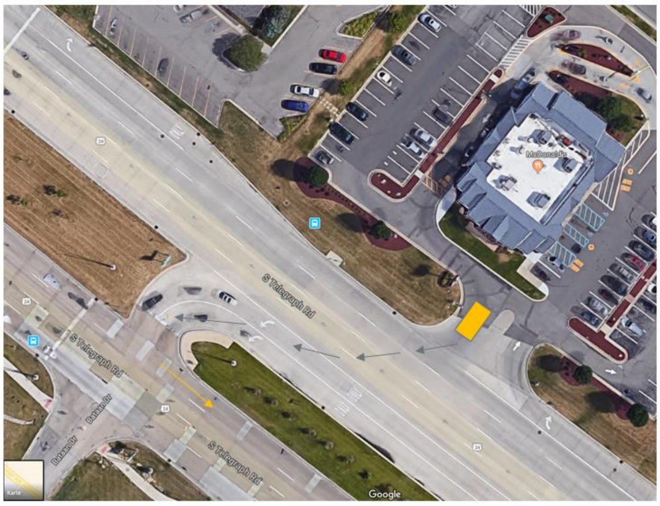
A vehicle identifies a free parking space on the side of a road and cooperates with neighbouring parked vehicles to inform them of the planned parking action and asks them to 'make room' to carry out an efficient and fast parking manoeuvre.

To facilitate inner city parking and using the limited available space, the parked vehicles can slightly move to facilitate or enable one more vehicle parking in a narrow spot. The communication would firstly activate the vehicles' 'wake-up' procedures and initiate an automated movement. For this, information about the required space and highly accurate positions of the parking spot are required, and support for the parking request by the parked vehicles needs to be communicated.

Use Case complexity specifics: Group-Management, Multi-Vehicle-Action, Action-Variety**,** Heterogenous-V2X-Capabilities.

5.2.8 Cooperative Traffic Gap

A host vehicle intends to pull into a large road and needs to cross multiple lanes, so it asks vehicles already circulating on the road to cooperate by opening a gap to allow the Host Vehicle (HV) to enter the traffic and cross (manoeuvre) safely. Similar to the Interactive VRU Crossing Use Case, approaching vehicles temporarily form a group to enable the safe manoeuvring of the vehicle.

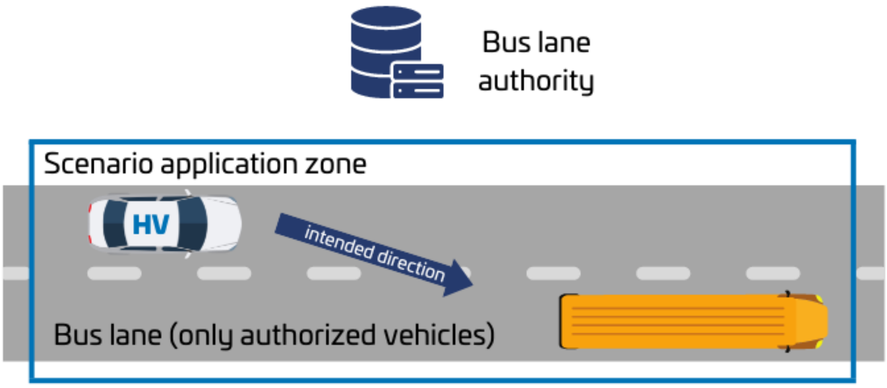


To facilitate a vehicle crossing dangerous and heavily frequented roads, the vehicles occupying the multiple lanes and the crossing vehicle need to communicate in order to determine the time of the manoeuvre next to the planned speeds of the affected vehicles. Here again, coordination on multiple aspects is required.

Use Case complexity specifics: Group-Management, Multi-Vehicle-Action, Action-Variety, Heterogenous-V2X-Capabilities.

5.2.9 Bus Lane Sharing

With the Use Case Bus Lane Sharing, temporary access to bus lanes can be granted to certain vehicles by a road authority or city. This can be used to improve the road use and traffic efficiency. Incidentally, the revocation of access to bus lanes can be triggered if the vehicle is likely to disturb or obstruct an approaching bus.



When a vehicle detects the availability of a dedicated lane, such as those assigned to busses and taxis, it can request access from the local road authority who responds by granting or rejecting the request. Furthermore, the local authority then continues to communicate with the vehicle to verify or modify the permissions and access.

Use Case complexity specifics: Action-Variety.

6 Comparison of the Use Cases

This section will present the determined commonalities and differences established and detected between the Use Cases.

All use Cases support the improvement of safety, comfort, and traffic flow when implemented. The Service-Level Requirements (SLRs) of the individual use cases can be found in [1] and [2]. Their requirements were considered when evaluating the differences and commonalities.

6.1 Determination of Commonalities

This exercise has found the following aspects to be common among all Use Cases:

- A message exchange is necessary to communicate intent, acceptance, participation or similar conditions among the participants.
- The forming of a communication group before a complex interaction manoeuvre is required. This can be dedicated communication between Use Case participants and other V2X vehicles in the surroundings or be between only two participants or more, which then becomes a communication group. Generally, this group communication can only be 'understood' by the involved participants.
- The Use Cases require some sort of negotiation to align the requirements of different participants with regards to the manoeuvre of interest.
- A Use Case initiation is needed; regardless of the physical location, all Use Cases have a starting and thus an ending point.
- The manoeuvres can only be executed once all participants know the conditions surrounding the user story of the Use Case.

- Reliable Communication is necessary. This goes for the exchanges during the decision-making process but also for the messages controlling manoeuvres.
- Feedback and monitoring among the participants is necessary. During movement and decision-making, the different participants monitor the behaviour, movements and messages of other participants as a verification mechanism.
- All Use Cases can be separated into different sections: (1) Group Forming, (2) Group Maintenance, and (3) Group Dissolving. Some Use Cases only demonstrate Phase 1 and Phase 2, and no further phases than the three were identified. The three phases will be further presented in Chapter 7.
- Some basic data types are always required for all Use Cases. Information types such as timestamps, temporary vehicle IDs, and different Use Case-related IDs need to be communicated on every exchange and for all Use Cases.
- Any message exchange or planned manoeuvre needs to have a fail-safe system. If sudden communication issues or exceptional situations such as actuation break-down or emergencies take place, the Use Case still needs to function or be aborted safely. Therefore, for every situation in the Use Case, all potential execution errors need to be covered in the development and implementation.
- Close to the above, exception handling needs to be developed for all these stages

6.2 Determination of Differences

Between the Use Cases there are many differences considered when further evaluating their application:

- Even though non-connected vehicles are considered in the implementations/user stories, this affects each Use Case individually, therefore the approach to non-connected vehicles has to be considered case-by-case for the different steps.
- The execution length of a Use Case can vary widely in time. While some Use Cases are very time-sensitive and require fast planning and execution of a couple of seconds, others can take place with significantly longer delays (up to minutes). This does, however, not correlate to safety critical aspects in the Use Case. This factor can also be affected by the environment in which the Use Case takes place.
- Further differences between the Use Cases are the data required from the different participants. During the different exchanges the required data varies due to a range of possible factors: the quantity of involved participants but also the quality/type of data can alter datasets, while the sequence of exchanges can range from a data-intensive message to a simple acknowledgement stating agreement.
- Some data elements are valid to only one of the Use Cases or even one step within the Use Case process. This does not mean the data may not be used by other Use Cases (not evaluated during this Work Item).
- Different Use Cases require different degrees of data privacy. While some require a strict communication of information to the communication partner, others can be implemented with a broadcast approach, as the data is less sensitive.
- Only in some Use Cases a dedicated termination, later referred to as Group Dissolving [3], is explicitly required. For other Use Cases the termination can be implicit.

6.3 Other Aspects Noticed

Each user story is directly affected by the environment, surrounding participants, conditions, etc. This leads to variation in the execution of steps and it means that the Use Cases are affected by the intersection types, lane quantities, and so on. Therefore, in adapting to those different aspects, the Use Cases may vary widely in their user story from one another. The implementation of a Group Start or of Bus Lane Sharing will be individually adapted to the area and will not be adapted in the same manner, even though the location might be the same. This also goes with the use of different available communication links.

Additionally, a Use Case can be implemented with different degrees of complexity. It is most beneficial to keep the complexity as low as possible, however different complexity degrees can lead to different time ranges, vehicle distances, and other similar parameters.

7 Common Overarching Requirements

7.1 General Functional Mechanisms

With the analysis of the selected Complex Interactions and considering the aspects such as: different ways groups can be addressed and formed, participants join or leave Use Cases, reliability is achieved; specific mechanisms were identified which are recurring in the Complex Interactions. These mechanisms not only enable the analysed Use Cases but also prove useful for Use Cases not yet reviewed because they are generic in nature and thus relevant for any future Use Case with a level of complexity. These recurring mechanisms taking place during the whole group management are presented here.

7.1.1 Introduction

Within the work, three Use Case phases have been identified: (1) Group Forming, (2) Group Maintenance and Execution, and (3) Group Dissolving. The Group Forming phase ends when all relevant participants are gathered and when the Complex Interaction Use Case can start. The Group Maintenance and Execution phase starts when all relevant groups for the Complex Interaction Use Case have been formed and the Use Case is executed. It ends when the execution of the Complex Interaction Use Case has been completed. The Group Dissolving phase concludes when all involved participants are aware about the end of the Complex Interaction Use Case.

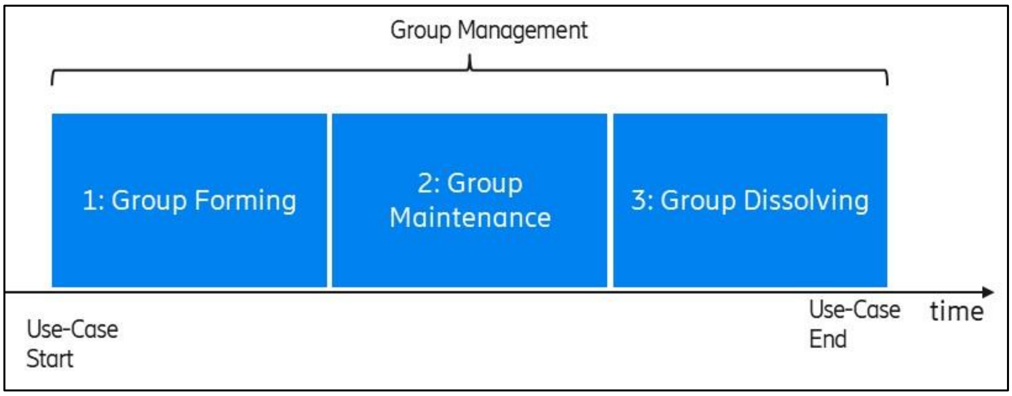


Figure 1: Group management phases

Many different mechanisms need to be implemented to enable basic requirements such as providing information, executing an order and implementing procedures needed to execute Complex Interaction Use Cases. Various mechanisms have been identified to enable these functional requirements, each serving a specific purpose in the execution of individual Use Cases. Additionally, all of these mechanisms can be resolved by using one of the different options available. Two different modes of functional mechanisms have been identified. First, the functional mechanisms can be executed in a passive/implicit manner. This may be thanks to restrictions on specific user stories pertaining to the Use Case, due to some parameters such as vehicle speed, traffic density, etc. where, for example, one mechanism is imposed by an authority such as an RSU. This means no explicit communication on the application layer is required between the Use Case partners to fulfil this imposed mechanism. The second identified method is the explicit exchange of the required information on the application layer between the Use Case..

From the analysis of the mentioned Use Cases, specific groups of mechanisms have been identified:

- Firstly, there are **General Mechanisms** present that enable and support Complex Interaction implementations. This may be throughout the whole Use Case implementation phase or during parts of it. These mechanisms are considered overarching and take place during the whole group management phase. They are not influenced by the step or phase in which the Use Case is in; rather they are present or called upon when the specific Use Case and the specific implementation design requires them. The other groups are linked to the different steps and processes taking place during Complex Interactions.
- The second group of mechanisms has been identified as providing functionalities around Use Case setup, **Group Forming** and group integration of vehicles. Since a communication group is required for a Complex Interaction between two or more Use Case participants, specific mechanisms have to solve the problem of group creation, negotiation, planning, and associated tasks such as group leader selection. All of these steps take place in this first phase.
- The third group specifically presents mechanisms taking place in the second phase of the Complex Interaction Use Case, described as **Group Maintenance and Execution**. The second phase of a Use Case has been identified to include any steps required for the execution of the Use Case taking place in line with processes set out in the first phase. These mechanisms all support Complex Interactions to ensure effective execution during this phase, from state tracking, group management, exception handling, to mechanisms ensuring the correct follow-through of the Use Case.
- Lastly, a fourth group has been identified as **Group Dissolving**. This group of mechanisms represents structures that take place when a Use Case has to be terminated after the manoeuvre or process is executed.

7.1.2 General Mechanisms Applicable During all Use Case Phases

Multiple mechanisms support all stages of the Use Case. These will be presented in this section.

7.1.2.1 Ensuring Reliable Message Exchange

Since the exchange of information for Complex Interactions relies on a defined message sequence it is therefore important to ensure that the message exchange can be relied on. This can be accomplished by using any functional mechanism or any parameters surrounding the Use Case.

Passive/Implicit Solution

By using mechanisms offered in different layers of V2X communication, such as having an upper layer protocol that includes a response and/or using AL-FEC, Addressing a global IP address, or using an underlying protocol mechanism (i.e. ARQ/HARQ on the radio layer), reliability can be increased without any explicit acknowledgement. Note, the underlying protocol may increase the reliability, but may not replace an explicit acknowledgement in all cases.

Explicit Solution

By explicitly sending a message confirming the reception of information, the reliability can be better ensured. This can for example be executed with an explicit flag of ACK/NACK or by a dedicated message on the application layer.

7.1.2.2 Exchange Message with Privacy, Confidentiality, Integrity, and Authenticity Features

Additional to the reliability, data privacy, confidentiality, integrity and authenticity needs to be ensured for any required interaction, without restricting the communication with the devices establishing the communication links. This requires signature sharing and forwarding mechanisms which enable the verification of messages within a group and its participants instead of a device-to-device level.

Implicit Solution

By designing the Use Case in a way that no data can be misused, and the information source and integrity can be determined, the safety can be ensured by design. This can be done by using the existing certificate and ID mechanisms for the critical messages, where the information is verified based on the signature/certificate. Other means can be used for V2X security/privacy mechanisms, such as encryption/decryption capabilities, which could be used for sharing information with confidentiality. In this instance the vehicle relaying information and data (both internally generated and integrated from other vehicles) into its message is effectively certifying its validity with its own signature.

Similarly, sharing certificates within a group can support functionalities such as indicating agreement among all signatories on what the content of the message is. This promotes trust among the receivers that the decision is shared because certificates of the group members are also attached to the message.

Explicit Solution

Another solution for ensuring the privacy and integrity of the information is to implement an explicit exchange of keys and encryption mechanisms. This can enable unicast and groupcast application layer communication.

For example, this can be implemented with dedicated proceedures for certificates and FIDs.

7.1.2.3 Long-Term and Temporary Privileges

In certain cases, a road user involved in a Use Case may need different privileges than other Use Case participants. This could be priority access to the communication channel or taking over resource allocation for other participants, but also receiving priority during critical execution stages of Uses Cases. An example for the first point would be an RSU managing traffic merges, or emergency vehicles traversing intersections for the latter. The device requesting the privileges would therefore take over the responsibilities such as triggering the Use Case and serving as a group lead.

Implicit Solution

Again, by designing the Use Case and message exchanges in a specific way, such temporary privileges can be implemented and ensured. This can be by allowing a certain device or priority type to receive automatic priority in a manoeuvre such as a lane merge.

Explicit Solution

A solution can be provided explicitly by enabling the exchange of a ‘privilege message’. When a vehicle requests privileges with such a message and by providing a type of confirmation by a higher instance ‘sponsor’ such as a government agency, the privileged access can be obtained.

7.1.2.4 Dynamic Negotiation of Capabilities and Parameters

In certain instances, the capabilities and parameters between Use Case participants need to be negotiated or communicated, as these vary from vehicle type and generation. This is, for instance, beneficial in situations where sensor information is to be communicated but the parameters of the data stream are not defined. Information that can be communicated for this purpose would include different parameters, such as capability sets or classes, which could be overlaid on a mapping ‘constellation’ and enable simpler communication of parameters using just one identifier.

Implicit Solution

Identical to some other enabler mechanisms presented above, this can be automatically implemented in the message exchange and Use Case design. This could, for example, be specified in advance for certain data formats and sensor stream types, or by enabling automatic selection depending on other Use Case factors, such as the quantity of participants.

Explicit Solution

To explicitly enable negotiation of such parameters, multiple options exist. Firstly, the negotiation can be explicitly implemented via the exchange of messages where the capabilities and requirements are communicated and agreed on between the Use Case participants. Another explicit possibility would be the imposed parameters by a Use Case leader (i.e. RSU or a vehicle leading the Use Case). Lastly, the parameters for the Use Case data parameters can be communicated during the setup phase where the general parameters, plans and trajectories are announced before the Use Case takes place. In this case, the potential participants can decide if the parameters suit them and can therefore opt in or out of the Use Case.

7.1.2.5 Exchange of Messages with High Payload Volume and a Resilience Requirement (Sensor Data)

If multiple parallel data-streams are needed to be transmitted by one user, they can take the form of multiple unicast streams or group/multicast streams. Unicast should be appropriate to deliver distinct information for different receivers, e.g. RSU providing different stream perspectives to different users. Otherwise, groupcast and multicast can be used to improve the communication link use. Different data quantity and quality will be required depending on the type of data-stream, the length of the transmission, and the latency requirements for the data. To ensure this can be adapted to the situation, a mechanism is required.

Implicit Solution

Implicit solutions across multiple layers can ensure that the availability of resources for different payloads or messaging frequencies can be achieved. By designating fixed protocol and coding profiles for the different involved protocol layers, smooth integration can be ensured.

Underlying protocol mechanisms:

- Unicast when it is the receiver
- ARQ or latency critical FEC and ARQ
- Multicast on Network and Transport when this can also be implemented on the physical layer
- FEC with ACK/NACK on independent layers
- Network and Transport Unicast with Application Layer replication/overlay multicast

Explicit Solution

By explicitly reserving resources, the sender can ensure the data-stream. Depending on the band conditions, different quantity and quality can be communicated with the requested communication frequencies.

7.1.2.6 Intent Sharing

In order for a vehicle to solicit the participation of other actors in a manoeuvre, it must have a mechanism to express which type of manoeuvre it wishes to engage in. Furthermore, there must be a common syntax through which different actors can differentiate between different Use Cases. For example, if a vehicle is going to be asked to help another to merge onto a highway, it must understand what type of manoeuvre it is being asked to agree to. By sharing their ‘intent’, Use Case participants communicate in which physical action they intend to partake or actively initiate.

Implicit Solution

Due to specific parameters detected internally in the vehicle (beacon messages, sensors, etc.), vehicles can estimate a remote vehicle's intent and 'know' which type of manoeuvres/information exchanges might be required from them.

Explicit Solution

By sending a message specifically formatted to contain intent information a vehicle can advertise its next actions to surrounding traffic participants.

7.1.2.7 Joint Decision Making

If a dedicated lead for a Use Case is available, this does not generally give the lead the authority to take a decision for the group automatically, hence the need for a joint decision-making mechanism, where all Use Case partners decide and agree on execution parameters.

Implicit Solution

An implicit method for this mechanism can be achieved during the design of the Use Case by clearly defining which parameters are to be prioritised or can be negotiated in a joint decision process. This can, for example, be in the case of a speed parameter negotiation where the maximum speed of a vehicle may be limiting the range of motion and the defined Use Case does not allow certain parameter ranges.

Explicit Solution

Again, various mechanisms exist to provide a solution for this restriction. The first option would be the dedicated decision of a higher instance Use Case participant permitted to take such a decision through the authorities, such as an emergency vehicle or an RSU. This does not allow joint decisions, but rather one taken by a higher 'instance' among the different options provided and planned/requested by the other participants. The second option is a decentralised voting mechanism. By distributing the different possible decisions, Use Case participants can then vote which option suits them and the majority, or the least common denominator, would be chosen to be executed. Multiple research is underway in this area[1]. This 'distribution' of options must be made through information exchanges such as direct messaging. Thirdly, there is an option to transfer the voting mechanism to a dedicated neutral entity that is able to determine the parameters. This can be a local device or a network infrastructure element.

Manual Solution

In this specific case it is possible that a manual trigger may be a useful option. If a Use Case participant actor can make a decision suiting him/her such as trajectory proposals by a navigation system corresponding to different interests, the manual trigger could prove efficient in an environment of mixed levels of autonomy.

7.1.2.8 Identification of a Remote Vehicle's Position

In certain instances, it is useful not only to identify a vehicle by its messages and track an entity over time in a facility such as a Local Dynamic Map, but also to be able to estimate the physical position of the vehicle vis-a-vis the tracker's own location. This enables many uses thanks to unicast being capable of handling, for example, requests for sensor streams or to implement a Use Case.

Implicit Solution

Multiple alternatives exist to improve identification accuracy via implicit means, all of which rely on optimised positioning mechanisms. If the position of the 'ego vehicle' can be established with very low uncertainty and a granularity of tens of centimetres, the relative position of surrounding and 'beaconing vehicles' can be estimated without any additional messaging. Added mechanisms such as beam forming, diversity or MIMO can also increase positioning reliability.

Explicit Solution

Several options also exist for explicit identification. The first is better suited to vehicles where communication of identifiable information is not critical and does not infringe on data rights such as platooning with vehicles from the same company. This can be achieved by explicitly detecting number plates or exterior vehicle features and checking them from

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[1] Tactical Decision-Making in Autonomous Driving by Reinforcement Learning with Uncertainty Estimation | IEEE Conference Publication | IEEE Xplore

a list of saved parameters. However, these parameters need to be saved in the vehicle's system beforehand to enable such a function. Two other options are possible where the exchange of personal data does not take place and the position of the requested vehicle can only be of use during and for the execution of a Use Case. Both systems consist of a combination of sensors/cameras and direct exchange of information. Here, the first possibility is where the vehicle requests an action to be executed by the remote vehicle, which is then picked up by the ego vehicle's sensors/cameras. This could, for example, be a wiper movement or light flashing. By picking up this behaviour the vehicle that requested the action can now associate the addressed vehicle ID with a physical vehicle. The second option would extend the first one slightly by reversing the information flow. The ego vehicle requests a sensor/data-stream from a vehicle and then executes an action to identify itself in the forwarded stream. This would enable the vehicle to execute whichever action it likes to identify itself without even providing any information to the vehicle that has forwarded the data-stream.

7.1.2.9 Misbehaviour Detection

To effectively recognise if all Use Case participants or potential Use Case participants, such as surrounding traffic participants, are manoeuvring and interacting according to traffic rules and agreed-on or communicated parameters, it is important to provide mechanisms enabling the users to verify if that behaviour is correct.

Implicit Solution

By reviewing the misbehaving vehicles' cyclic beacon messages and comparing their content to cyclic beacon messages from other users, by tracking objects in the LDM, or by using other data such as sensors, video information or backend data, a vehicle can detect the misbehaviour of another vehicle. Depending on driver/vehicle intent, a decision can be made on how to use the misbehaving's vehicle data to ensure safety and security, and what further actions should be done in these regards.

Explicit Solution

Misbehaviour can be explicitly detected by verifying Certificates. If the vehicle is registered as a misbehaving entity, the messages from that vehicle can be ignored and duly reported.

Furthermore, by using the Use Case Awareness Confirmation, a verification can be requested to ensure that the information has indeed been received correctly. If this confirmation is not sent, the requesting vehicle can determine the misbehaviour of the non-responding vehicle.

Note: A method is required to determine the difference between misbehaviour of any type and potentially less risky actions (i.e. slightly altered movement by the participant). If the vehicle moves at a slightly faster speed or merges at a slightly different location than announced, a tolerance level needs to be implemented.

Note: All Use Cases need to have a way to handle exceptions or vehicle failures. Therefore, all possible situations need to be accounted for and a mitigation approach selected.

7.1.2.10 Avoid Active Misbehaviour

Misbehaviour can cause a lot of problems in the execution of Use Cases, hence avoiding it at any cost is critical to ensure efficient, secure and safe manoeuvres. However, approaching the problem can add complexity because misbehaviour needs to be confirmed – not every exceptional situation might be a misbehaviour.

Implicit Solution

By carefully designing the Use Cases, implemented data types and message exchanges considering the different ways misbehaviour might take place during an implementation, the system can be made robust without having to issue additional messages or verifications. This can automatically exclude misbehaving participants without adding any messaging overhead.

Explicit Solution

By detecting the misbehaviour of different road users, such as comparing their planned manoeuvres to actual manoeuvres, detecting unauthorised certificates or directly receiving conflicting information, misbehaviour can be confirmed. Potentially, this can be forwarded to leading entities such as Control Functions and V2X AS, which would confirm and forward the misbehaviour information, allowing all vehicles in the vicinity to be informed about a misbehaving vehicle. This can then be further used by Use Case leaders to eject the misbehaving vehicle from cooperative Use Cases if the risk of misbehaviour is still present and poses a danger.

7.1.2.11 Avoid Unintended Use of a Use Case

Generally, Use Cases are related to a set of parameters such as specific vehicle densities, locations, etc. It would therefore not be useful or dangerous for certain Use Cases to be triggered at instances where manoeuvres are actually not planned. It is important that accidental implementations do not take place. On the other hand, if vehicles asked to participate in a Use Case opt to reject the request, the beneficial effects of the implementation are equally compromised.

Implicit Solution

To motivate participation, the activation of the system should demonstrate to the owner that implementing it provides a benefit to the ego vehicle in some instances and at the same time agrees on playing an accommodating role for the same behaviour when other vehicles are in the benefiting position. It is assumed that the activation is taking place during the vehicle setup phase by the owner and thus any participation in such Use Cases is therefore either accepted or rejected during any driving. The processes of that Use Case are then clearly defined by designing message exchanges and triggering parameters strictly. To avoid unintended use such as preventing wrong locations, a Use Case needs to be clearly defined and communicated data components described without which the implementation or user scenario is rendered impossible. This, for example, can be controlled by having an RSU implementing an intersection Use Case where the location cannot be mistaken.

Explicit Solution

To explicitly avoid misuse, incentives can be implemented to signal a so-called ‘beneficial motivation’. By for example enabling micro-payments which are signed and documented in backend systems, an agreement and consensus can be achieved. Another explicit way of bypassing unintended use is the addition of specific trigger permissions. By adding and sending a data flag with a specific permission attributed by a higher instance, such an RSU, permission to implement the Use Case is given and therefore the misuse is limited.

7.1.3 Phase 1: Group Forming

All mechanisms presented in this section are explicitly dedicated to processes required for initiating a Use Case among the different participants. Here, each mechanism will be briefly explained individually.

7.1.3.1 Identification of Use Case Scenario and Use Case Selection

Since Use Cases can take place in varying areas, times and participant densities, it is required that mechanisms are provided to identify when said Use Case should or could take place. Additionally, a Use Case can have multiple scenarios based on vehicle densities, intersection types, vehicle speeds, and so on.

Implicit Solution

A solution can be represented implicitly by designing the Use Case in a way that the identification of a scenario and Use Case is set by parameters that can be detected by different participants. This can be by using beacon messages (CAM and BSM), GNSS locating of the vehicle in a matching location, but also ego speed, acceleration, etc.

Explicit Solution

By explicitly inviting participants in the immediate environment to take part in a Use Case, a scenario and adequate Use Case can be communicated. This can be based on the ‘interest response’ of vehicles, the quantity of responses and other parameters. Based on such exchanges, the perception and comprehension of different participants with regards to the correct choice of Use Case and user scenario can be determined. This can be initiated by vehicles, infrastructure or networks.

Another possibility is a request through a backend system. If a vehicle enters an area and estimates that a Use Case can or would take place in such an environment, a request to a backend system containing information about the location can be executed. The backend system’s response will then attribute and inform the vehicle of the right Use Case to select and which scenario applies.

A third option is the simple communication of the Use Case from a vehicle to other participants. If a vehicle selects to execute a Use Case, it can simply communicate an intent to execute a selected Use Case. This can be from any potential Use Case participant or from devices with a higher level of authority such an RSU.

Furthermore, the infrastructure can take a larger role by communicating a strong recommendation that a Use Case be initiated for a certain area. The implementation would still be up to the participants, but such a recommendation would come with a reasonable benefit.

7.1.3.2 Identification of Possible Partners for a Complex Interaction

The purpose of this mechanism is to identify the required or potential participants in the Use Case and to form one or more groups of possible/relevant partners for the Complex Interaction taking place within it.

Implicit Solution

By designing and implementing the Use Case in a specific way, the exchange of information for forming a group, identifying the participants and describing the sequence of exchange can be implemented implicitly, where a dedicated group and participants can be selected based on a set of parameters being met in a specific circumstance or environment, such as in certain lanes, at certain speeds, or similar.

Explicit Solution

Participants can communicate (broadcast/multicast) their intent and identify possible partners by awaiting their feedback/response. A participant can volunteer for a role and request devices to take on certain responsibilities. In this case, candidates could be suggested by available map information or backend instructions to the initiator.

A participant can volunteer to participate and report capabilities to the group leader, the role assignment would be executed by a group leader (infrastructure component). A participant can be explicitly requested to participate by a higher authority, this could for example be the case for accommodating emergency vehicle manoeuvres.

7.1.3.3 Group Lead Selection

The implementation of Complex Interactions almost always requires a Use Case leader who takes over coordination and decision making in agreement with the other participants. Therefore, a suitable leader should be selected. To implement some Use Cases, the selection of a leader is obligatory. There are many ways in which a leader can be selected.

Implicit Solution

By implicitly designing a Use Case, determining its leader can take place automatically based on parameters or Use Case triggers. This can be a higher instance such as an RSU who takes over the responsibility of trajectory planning through an intersection, or an emergency vehicle who has the right to command other road users, by design.

Explicit Solution

A group leader can in some instances be selected by explicit negotiation. When Use Case participants all play a role in the Use Case and none have a higher permission status before the negotiation, a suitable leader can be selected by specific vehicular parameters such as the position in the queue, its size or by the fact that it is the originator of the Use Case request. This can also take the form of an explicit negotiation between the potential and interested vehicles in deciding who should take on the role.

In a variation of this first mechanism, a group leader can also be selected by request. If a participating vehicle detects and considers another participant to be suited, it can propose that this vehicle take on the role.

A third mechanism can be implemented, where a higher instance such as a backend system or RSU assigns the role of group lead to a vehicle based on known parameters. This method enables a neutral selection by an actor who stands to gain no benefit from its role in the Use Case. In a slightly different variation of the third mechanism, the backend system or RSU takes on the role of Use Case leader.

Note: The selection of a group lead and determination of group participants can be very closely linked.

7.1.3.4 Decentral Group Forming

To enable Use Cases where specific groups need to be formed but no dedicated leader is announced or allowed by design, a mechanism needs to enable the forming of groups on the application level.

Implicit Solution

With the design of the Use Case, if parameters are satisfied for a defined implementation, the group is formed implicitly. These parameters can be based on beacon information but also vehicle speed, vehicle density, and so on.

Explicit Solution

The potential participants identified in a previous step can explicitly negotiate their interest in participating by themselves, announcing their interest or by being requested by other participants. This can be in the form of group member proposal, agreement, rejection, and counterproposals.

As with the selection of a group lead, a higher instance such as an RSU or infrastructure can impose/propose the participation of a vehicle in a group.

7.1.3.5 Decline Participation

A participant may decline the invitation/request to participate in a Use Case during setup (when invited) for justifiable reasons, such as a hard-braking request that cannot be achieved. However, if the reason is malicious or simply disinterest, possible mechanisms should be available to deal with these situations (See 6.2.10).

Implicit Solution

An implicit solution is possible when the design of the Use Case allows for a request to be declined/rejected. If a vehicle is requested to participate in a Use Case but the vehicle does not respond, this can be taken as a direct indicator that it is declining or refusing to join. To clarify this, other mechanisms on lower layers, such as HARQ or response timeouts, can be used to avoid that such 'unresponsiveness' is not due to a different reasons. Not responding would also correspond to the behaviour of non-connected vehicles, which needs to be considered for all Use Cases.

Explicit Solution

The first explicit solution would be messaging the Use Case participants that the ego vehicle is not participating in the Use Case. Here the involved participants are all aware and further problems can be avoided. If this intent is communicated at earlier stage of the Use Case setup, the vehicle's refusal message would be earlier in the process of group creation and thus be able to exclude this vehicle from any further communication implemented for the Use Case.

7.1.3.6 Rejecting a Member

Under specific circumstances certain vehicles might need to be ejected/rejected from a Use Case scenario. This can be due to external factors such as weather, location, traffic and vehicle density, etc. It can, however, also be due to the rejected vehicle's own parameters such as vehicle weight and size but also technical capabilities or evidence of prior misbehaviour.

Implicit Solution

Specific parameters might automatically exclude vehicles. This could, for example, be the maximum quantity of involved participants reached for a Use Case implementation, the physical limitations of the rejected vehicle such as vehicle weight, or the type of Use Case. In this instance, the parameters are set for each Use Case and the simple detection of a mismatch between the parameters automatically excludes the vehicle.

Explicit Solution

Rejecting a vehicle explicitly can be executed by directly communicating the decision to the concerned vehicle. This rejection can be from the Use Case Leader or a higher entity such as a V2X AS. The reason for the rejection must be valid, such as misbehaviour or the fact that participation is impossible due to certain vehicle parameters. How such a decision is taken depends on the Use Case and the scenario, where such parameters must be defined.

7.1.3.7 Leaving a Group Before the Planned Action

If a Use Case participant has agreed to participate in a Use Case but the execution of the agreed Use Case has not yet started, the participant can choose to leave a group. This could be a group decision because there are Use Case parameters limiting the participation of the vehicle, a technical problem experienced by the vehicle itself or other urgent situations.

Implicit Solution

A possible implicit implementation would be the vehicle ignoring a request from other vehicles by neglecting to respond to their communication attempts. With a specific threshold, the other Use Case participants become 'implicitly' aware that the vehicle has left the communication group.

Explicit Solution

Another way to communicate this can be by explicitly sending a message indicating the vehicle's departure from the group. With this, all participants are immediately aware once the message is received.

Note: This function is very similar to Section 7.1.4.4 with the difference that here the vehicles have not started moving.

7.1.3.8 Cancellation of the whole Use Case

If a Use Case instance has to be cancelled completely due to an uncontrollable situation, a group leader or higher instance can indicate this by completely cancelling the use case. This is possible because the Use Case is only at a preliminary planning stage.

Note: A fallback mechanism, as presented in Section 7.1.4.6, could take its place, but the cancellation and initiation of a new Use Case might be more effective during the Group Forming Phase. This may depend on the Use Case.

7.1.4 Phase 2: Group Maintenance and Execution

Mechanisms presented in this section serve the purpose of controlling, managing, and executing the Use Case. Equally, each mechanism will be briefly explained.

7.1.4.1 Initiation of a Complex Interaction

Since Complex Interactions would often take place in situations where they are directly required, they do not take place continuously. To correctly identify traffic scenarios and situations where the implementation of such a Complex Interaction Use Case would be a benefit to traffic participants, it is important that the trigger is correctly identified and advertised. As such, the initiation of the Use Case needs to be effectively managed to ensure all negotiations and agreements for the Use Case manoeuvres are executed at the correct time.

Implicit Solution

One possible option is that the execution parameters, such as vehicle speed, map topology, traffic light stages, etc. are met and validated automatically with theenvironment in which the Use Case takes place. This can be based on an explicit negotiation of said parameters in a previous Complex Interaction stage.

Explicit Solution

Two other possible mechanisms have also been identified. If the initiation of a Complex Interaction is not self-evident (possibly due to unclear implicit parameters), explicit agreement/negotiation of a course of action via messages can be used.

A second clear explicit method would be the communication of an initiation message by a leading entity, such as the group lead or an instance from a V2X AS. By explicitly communicating the beginning, all Use Case participants are clear on the future actions that are to be taken by them.

7.1.4.2 Synchronised State Tracking

To be able to track and verify the actions of members involved in a Use Case during an execution, whether a manoeuvre specifically or to track positions within a vehicle train, a mechanism enabling state tracking is required. By this, continuous updates can be received/given to verify and confirm the correct and agreed-upon execution of the Use Case. By making this mechanism synchronised, a further level of assurance is given to the group/leading vehicles, as relevant Use Case-specific information is communicated, enabling each vehicle to adapt accordingly.

Implicit Solution

This mechanism can be enabled by implementing already existing messages and a system of beacon messages. By providing regular status updates through broadcast/multicast to all surrounding Use Case participants, a vehicle's information dissemination enables a form of 'state', or current status, tracking. This is, however, restricted by the regulated message generation and message content, which might not be suitable as status updates in specific situations, such as dense traffic scenarios where the beacon message update frequency is reduced or situations where Use Case- specific information is explicitly required for the state tracking.

Explicit Solution

In situations where the implicit method is not sufficient for the execution of a Use Case, a dedicated information exchange can be established. This can be executed with the implementation of a dedicated message sending the required information at the required rate. There are two possible implementations of this method. Firstly, 'lamport timestamps' can be implemented via regular message dissemination. This provides some stability as the message sending rate can be high enough to provide robust information reception, regardless of potentially dropped messages over a congested channel.

The second option would enable the same mechanism but with explicit ACK for every state tracking message sent. This would also strengthen the link.

7.1.4.3 Leaving the Use Case Before Finalisation of the Planned Action

A participant may leave an ongoing Use Case and drop out of a Complex Interaction Use Case at any point in time during the execution phase. The reasons for this can be varied, such as an emergency action by the vehicle due to a sudden obstacle or because of malicious behaviour. Mechanisms should be available to avoid this kind of misuse.

Implicit Solution

The implicit solution would be identical to the function described in Section 7.1.3.3. By ignoring and not responding to messages of the Use Case during this phase, the other members can assume that the vehicle chooses to no longer participate in the Use Case.

Explicit Solution

Two explicit methods have been discerned to enable a vehicle to drop out of a Use Case during this phase. The first option would be that the vehicle explicitly communicates its intent to leave. This can be done by sending a message to all actors involved in the Use Case. By leaving the group, it is assumed that the vehicle no longer participates in the Use Case.

The second option would be the vehicle's explicit refusal to participate any further. Though the mechanism is the same as the firsts option, the content of the message would be different in that the vehicle can still be part of the group. This option can support more complex Use Cases where multiple manoeuvres and groups of different levels may be present, and a complete exclusion can be avoided to minimise the impact on those manoeuvres. Additionally, such a response may enable further Use Case negotiation to execute further manoeuvre steps under different conditions previously negotiated. This also avoids the complete cancellation of the Use Case.

7.1.4.4 Cancellation of the Whole Use Case

If a Use Case instance has to be cancelled completely due to an uncontrollable situation, a group leader or higher instance can completely cancel it, and all participants are made aware that no further action is planned. In this case, the Use Case execution will have completed the planning phase and even entered the execution phase, but the Use Case should not/cannot be fully executed as planned.

Implicit Solution

The leader stops any communication directly Addressing the Use Case group or does not respond to any communication. As the group leader with assigned responsibility, this can be implemented to indicate the cancellation of the Use Case.

A second implicit manner to implement a cancellation would be when a set of determining parameters are not met any longer and the dissolution of the use case is automatically apparent to all participants (mutual understanding).

Explicit Solution

Use Case participants or the Use Case leader explicitly indicates the cancellation of the Use Case via direct messaging.

Note: The Use Case as it was initiated can no longer take place, but if the initiator still wants to execute, for example, a merging manoeuvre, this does not preclude the requestor from restarting the Use Case from the beginning. This can be with completely different participants, for example.

7.1.4.5 Joint Fallback

The Joint Fallback mechanism is a less radical action than, for example, cancelling the whole Use Case. In certain instances, the planned manoeuvre does not need to be completely cancelled, but may revert to a previous stage; renegotiating parameters, for example, might be enough and the Use Case can still take place under different conditions. This mechanism enables the Use Case to carry on even when exceptional situations have interrupted the planned proceedings.

Implicit Solution

The implicit implementation for Joint Fallback may be automatically activated thanks to the Use Case design. This does, however, require detailed descriptions and fallback processes for all stages and message exchanges of the Use Case, which may prove complex.

Explicit Solution

If one Use Case participant explicitly messages other participants by sending a Joint Fallback flag, it is understood that the Use Case will still take place. This action also directly indicates that the parameter negotiation is recommencing. With this, other Use Case participants can propose alternate manoeuvre solutions. If all participants agree on a new negotiated manoeuvre, the Joint Fallback is performed (or a joint Use Case abort decision is issued). If all vehicles agree on multiple manoeuvres, the initiator of the Joint fallback decides which one to go for.

7.1.5 Phase 3 Group Dissolving

7.1.5.1 Finalisation of a Complex Interaction

To indicate that a Use Case is finalised and completed, a mechanism is required which can indicate this termination. After a manoeuvre is executed such as a vehicle group movement or that a group has split up this finalisation clearly indicates that the Use Case is completed.

Implicit Solution

By implicitly designing the Use Case in a certain way, the termination of a Use Case automatically takes place once the movement or messaging of a certain type is completed, for example the coordination of vehicles crossing an intersection. When the vehicles have successfully manoeuvred through the intersection, the Use Case is considered terminated.

The same can be achieved by implicitly verifying the existing beacon messaging and determining if the vehicles are still affected by the situation covered by the Use Case. If all participants' beacon messages indicate their outward movement from the Use Case location, the Use Case can be considered as executed.

Note: The assumption is that general information acquired via BSM/CAM indicates the vehicle positions and the effective execution and dissolution of the Use Case factors in indicators such as vehicle speed and parting trajectory.

Explicit Solution

By explicit communication, the group members can signal to other participants that their manoeuvre, or their part in the Use Case, is finished and they are therefore no longer involved.

7.2 Data Elements

Next to identified mechanisms required for execution, different data types have been identified which facilitate the Use Cases in the evaluated implementation. These data types follow a specific purpose and are required in different steps of the Use Cases. It is estimated that similar types of data with similar mechanisms will be relevant to future Use Cases as well.

7.2.1 Data Element Characteristics

Considering the different Use Cases, the data elements considered in the implementations are presented with their corresponding association with the mechanisms presented in Section 7.1.

7.2.1.1 Generally Used Data Elements

Data Element	Description
Application Identifier	ID used to delineate the Use Case (from a list of fixed identifiers for each Use Case)
Group Identifier	To ensure continuous addressability of the group members this can not efficiently be achieved by Addressing individual vehicle IDs but instead can be resolved with a dedicated group ID
Initiation Identifier	ID used for a specific initiation of the Use Case (multiple initiations could be executing at the same location at the same time)
Message Identifier	ID used to mark the specific message of the Use Case (from a list of fixed identifiers for each message type)
Temporary Vehicle ID	The vehicle's identifier (as known in CAM and BSM) Can be further presented as 'requestor' vehicle ID, or participant vehicle ID, or group leader ID to identify the roles
Timestamp	Specifically indicates the time of the message generation

7.2.1.2 Data Elements Related to Identifiers

Date Element	Description
Application Identifier	ID used to delineate the Use Case (from a list of fixed identifiers for each Use Case)
Group Identifier	To ensure continuous addressability of the group members this can not be efficiently achieved by Addressing individual vehicle IDs but instead can be resolved with a dedicated group ID
Initiation Identifier	ID used for a specific initiation of the Use Case (multiple initiations could be executing at the same location at the same time)
Message Identifier	ID used to mark the specific message of the Use Case (from a list of fixed identifiers for each message type)
Target List of participants	List of vehicles' temporary vehicle IDs explicitly stated in a message to for example request participation in a maneuver, or to identify their interest
Temporary Vehicle ID	The vehicle's identifier (as known in CAM and BSM) Can be further presented as 'requestor' vehicle ID, or participant vehicle ID, or group leader ID to identify the roles
Temporary VRU Identifier	VRU identifier similar to the temporary vehicle identifier

7.2.1.3 Data Elements Related to Manoeuvre Data

Date Element	Description
Manoeuvre Data	Data that is necessary to agree, plan and execute the cooperative manoeuvre. For example: • Free parking slots • Planned or desired trajectories • MAP-like data • SPAT-like data • Time to start • Vehicle type of the participant • Priority level of the Use Case • Urgency of the Use Case • Reason code (indicating a decision of the sender) • Agreement flag • Rejection flag • Distance to vehicles • Motion trajectory for a planned manoeuvre or any kind of trajectory
Participant Capabilities	Data that is required to consider the diverse capabilities of the target group during the negotiation. For example: • Max. velocity • Max. acceleration • Vehicle speed, intended speed • Velocity range • Acceleration range • Accuracy for different communicated data

7.2.1.4 List Types

Date Element	Description
List Types	List types in combination with the above data elements: • Tuple of vehicle ID and decision flag • Tuple of vehicle ID and possible speeds • Tuple of GNSS positions and timestamps • Velocity array

7.2.1.5 Error Handling

Date Element	Description
Error Code	Enables participants to identify a problem
Vehicle Certificates/Signatures	The Certificates of other users can be forwarded to establish mutual trust within the group and to indicate agreement on a manoeuvre or decision

7.2.1.6 Others

Data Element	Description
Timestamp	Timestamps can indicate multiple values to execute manoeuvres: • Time remaining to the manoeuvre • Manoeuvre starting time • Message/information timeout • Message send time
Counter	With a counter, the number of message exchanges can be tracked and the current state of the Use Case can be quickly identified

7.3 Message Flow

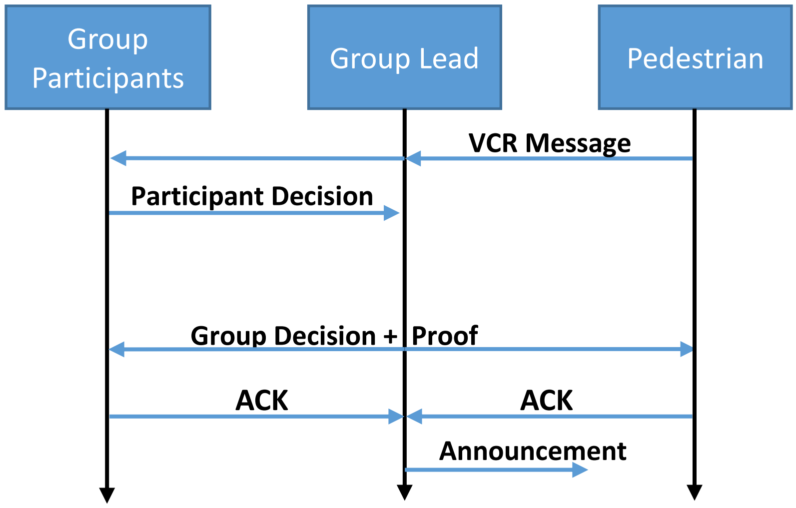
As with Complex Interactions, the data flow and information exchange order have an influence on the way the Use Case is implemented. As such, the three Use Cases Interactive VRU Crossing, Group Start and the Implementation of Lane Merge were looked at in more detail to gain understanding on what aspects need to be considered when implementing a Complex Interaction Use Case. From the evaluation, the following information flows and exchanges between Use Case participants were determined. The flows presented here were the best possible implementation option while ensuring critical aspects were all satisfied, including:

- Safety-critical data availability
- Least required messaging possible
- Consideration of information sequence
- Consideration of participant selection and determination

It can be seen in the sections below that each Use Case implementation therefore differs, and this is directly related to the Use Case definition itself and resulting requirements in the implementation.

7.3.1 Interactive VRU Crossing

The following represents the information exchanges as evaluated for the Use Case Interactive VRU Crossing. Here, the participants include one VRU initiating a crossing request and multiple vehicles accommodating the manoeuvre.

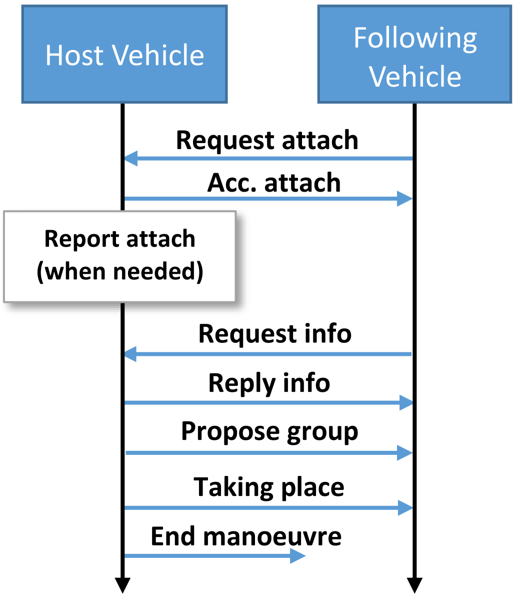


The implementation was considered as follows:

1. A pedestrian asks to cross the road at a specified location and communicates this intent to relevant vehicles, especially to a vehicle it has identified to play a role in the Use Case. The message also contains general information surrounding start time, speed and so on.
2. The other requested participants, aware of who was selected as lead by the pedestrian, confirm (or reject) their participation to the lead according to relevant Use Case parameters.
3. The lead vehicle takes on the responsibility of checking the different responses of the participating vehicles, takes a decision on the parameters, and sends this information to all participants including the pedestrian.
4. The different Use Case participants acknowledge and confirm their participation with the selected parameters.
5. The selected group lead announces the Use Case execution to all surrounding listeners.

7.3.2 Group Start

In this evaluated implementation of Group Start, the vehicles sequentially attach themselves to a vehicle in front of them, while waiting in line at a red traffic light. These vehicles are all located within the same lane.

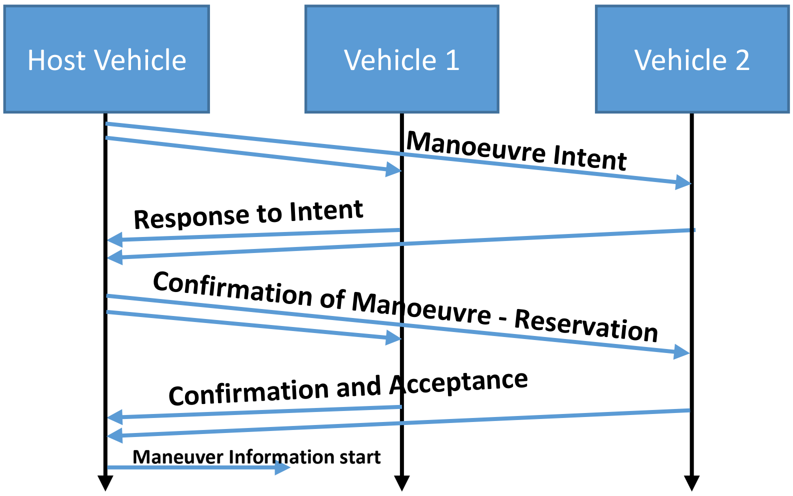


The implementation considers the following:

1. A vehicle approaches a vehicle in front, waiting at a red light
2. It requests the attachment to form a for the Use Case Group Start with specific conditions
3. The Host Vehicle confirms the attachment and (if present) informs the vehicle in front of itself of the attachment of a further vehicle
4. The attached vehicle requests information from the preceding vehicle to obtain Use Case parameters and conditions
5. The Host Vehicle provides the information to the requesting vehicle
6. The Use Case group is proposed/signalled by the leading front vehicle which ‘groupcasts’ a message to all participating vehicles
7. A start message is broadcast and vehicles start moving as agreed
8. State tracking based on beacon messages is executed by participants individually
9. An end manoeuvre message is sent by the leading/front vehicle to indicate the end of the Group Start manoeuvre

7.3.3 Coordinated, Cooperative Driving Manoeuvre, Implementation of Lane Merge

In this implementation of Lane Merge an initiating vehicle is requesting the accommodation of its merge onto a highway-type road and vehicles in that lane accommodate the request.



The implementation considers the following:

1. A vehicle needs to merge from an on-ramp and identifies potential participating vehicles
2. The vehicle communicates the merging intent with Use Case conditions to the potential participants
3. The potential participants confirm (or reject) their participation in the Use Case with the proposed conditions
4. The merging vehicle reconfirms to all the participants that the Use Case is taking place under the indicated conditions
5. The participating vehicle reconfirms the correctness of the manoeuvre and their participation
6. The vehicle broadcasts the manoeuvre to surrounding vehicles to inform them
7. When the merge location and time is reached, the vehicles provide the space for the merge as agreed
8. The vehicles individually track the movements of the participating vehicles with beacon messages
9. After the vehicles have completed their movement the Use Case is finished

8 Key Enabler Technologies

To enable the different presented structures required by the applications, the following Key Enabler Technologies were discerned. These represent 'enablers' in the V2X protocol chain that can effectively resolve and implement solutions for Complex Interactions. Their relation to the relevance and the benefits of their implementation for Complex Interactions is presented in the following two sections.

8.1 Addressability and Cast-Types

Multiple ways of casting communication to different vehicles on the different layers exist. There are three main different types of casting:

1. Broadcast

This is a commonly known and already implemented cast-type for existing V2X implementations. Participants can exclusively communicate the information to all surrounding participants who can receive the message.

2. Groupcast

This cast-type enables communication to a dedicated group of participants even though other participants in the area could be capable of receiving messages.

3. Unicast

This cast-type enables a participant to directly communicate with only one other participant.

With these cast-types, different needs from Complex Interactions can be resolved. There are various ways a communication can be cast to the receivers; this is linked to the different layers of the communication stack on which the casting is taking place.

With the availability of L2-Layer fields on the physical layer of the protocol stack, it can be indicated which kind of cast-type is to be implemented. LTE-V2X supports broadcast as the default addressability scheme on L2, while other cast-types like groupcast and unicast could additionally be supported by higher layers.

3GPP Addressability on L2 of NR-V2X allows/accommodates all three types. With the PC5 Sidelink implemented in NR-V2X, two new L2 addressability schemes were introduced, allowing more efficient and reliable PC5 radio-link usage. These addressability schemes are groupcast and unicast, which can be used as an alternative to the existing broadcast scheme.

NR-V2X PC5 group- and unicast support L2 reliability features such as L2 retransmissions present in broadcast over LTE-V2X. These features increase the radio efficiency and reduce the effort on higher layers. Still, higher layer acknowledgements or retransmissions are sometimes needed. Additionally, the retransmission system can increase reception probability within the defined range of the connection type selected.

Note: Applications with L2 broadcast can support similar functionalities to the L2 groupcast or unicast solutions, by using application-layer-specific addressing and response messaging.

Note: Although groupcast transmissions benefit from L2 reliability features like retransmissions, many groupcast message transmissions require an acknowledgement to confirm the reception. Such acknowledgements should generally use unicast communication, since only the sender needs to collect the acknowledgements.

The following schemes are used in the different Use Case realisations and have been identified for use in Complex Interactions:

- Broadcast: Every device in the proximity is addressed.
- Groupcast: Only a subset of devices in proximity are addressed. Two groupcast variants have been identified and are described below.
- Unicast: Only a single device is addressed.

8.1.1 Groupcast Subtypes

The groupcast communication scheme is further defined as two variants (on PC5 L2):

- Variant A (NACK-only[2]): A receiver of the Groupcast PDU is expected to send NACK for a negative acknowledgement, but not ACK for a positive acknowledgement. All group members use the same radio resource to send the NACK, so the sender (i.e. the NACK-receiver) cannot differentiate between the group members. The PDU carries range-limiter information and, with this, only the receivers that are within X metres (i.e. within range) from the sender of the PDU should send a NACK (when needed).

- Variant B (ACK/NACK): Each receiver of a Groupcast PDU should always reply with either an acknowledge (ACK) or a not-acknowledge (NACK) back to the PDU sender.

8.1.2 Addressing on Layer 2

For broadcast and groupcast communication, specific broadcast/groupcast Layer 2 IDs are defined and used. Receivers of broadcast/groupcast communication need to have the Layer 2 ID for receiving the specific communication. There are different group management schemes to provide the broadcast/groupcast Layer 2 ID to the receivers, which will be presented below. From the presented findings, there is a need to separate groups on Layer 2 (PC5) and on Application Layer (AL). A group on AL does therefore not automatically communicate over Layer 2 groupcast and vice versa.

For unicast, however, each vehicle has a dedicated receiver L2 ID which can be addressed to exclusively communicate with that vehicle. This ID is in the current form of standards taken from the ITS AID.

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[2] TR 137 985 - V16.0.0 - LTE; 5G; Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR (3GPP TR 37.985 version 16.0.0 Release 16) (etsi.org)

8.2 Application Layer Group Management

Groups are automatically forming for the implementation of Complex Interaction Use Cases. Here, the group is not evidently taking place on lower layers but instead is clearly present on the application layers. This means that within the application the participants are aware they are part of a group and in some instances know of the other members present in the group.

With the three phases of a use case execution presented in Chapter 7.1, the application layer group management and different realisation options for the group forming phase will be presented here. The realisation options described in this technical report are a bit different from the application layer group management options described in TS 23.287.

Application Layer groups can be dynamic or pre-defined:

- Pre-defined AL groups: An authority allocates a Use-Case-specific Layer 2 ID for a predetermined and fixed use; this can be either a Groupcast or Broadcast Layer 2 ID. For example: hazard warnings or EEBL may use pre-defined Layer 2 IDs, where all these use cases can only use this dedicated ID. Here, the group address (Layer 2 ID) can be saved on the firmware and devices enabled for this function automatically listen to communication intended for this group address.

- Dynamic AL groups: Layer 2 IDs and cast-type are dynamically allocated at run-time and distributed to group members by the initiator. Group members activate the reception by passing the Layer 2 ID and the cast-type to the PC5 Layer 2 entity. Example Use Cases: Group Start or Interactive VRU Crossing. Here, multiple Use Cases can execute simultaneously, e.g. multiple instances of Group Start at a multi-lane road, with different Group Layer 2 IDs.

Application Layer groups may use different PC5 cast types during the Use Case-specific communication (see Section 8.1). Specifically, dynamic AL groups can use uni-, group- and broadcast or a combination of them for the group management.

Within the work, the dynamically created groups were investigated. The group management for dynamic Application Layer groups is also following the Scheme (1) Group Forming, (2) Group Maintenance and Execution, and (3) Group Dissolving as presented in Section 7.1. The realisation of the Group Forming, in particular, depends on the Use Case needs.

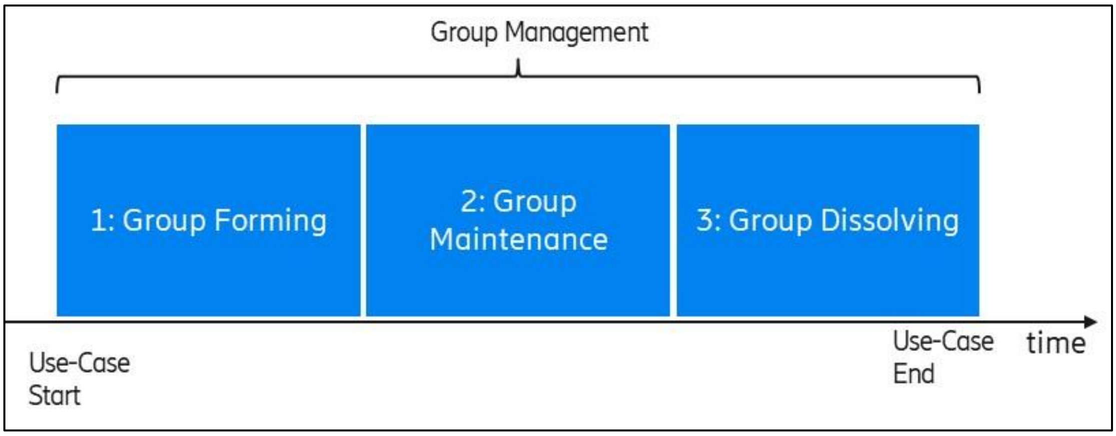

Figure 2: Group management phases

Two forms of dynamic Group Forming are identified during the study, specifically to leverage PC5 Groupcast.

- GF 1 (Publish/Subscribe): A group leader is publishing a Layer 2 Group ID to the surrounding vehicles, so that anyone interested and suited can join the group (see Use Case Group Start in Section 7.3.2). This enables a group to be formed from the beginning with all relevant participants already addressed.

- GF 2 (Selected invites): A group leader explicitly invites group members, e.g. provide a list of selected participants via unicast Layer 2 IDs together with the L2 Group ID and the cast-type.

In both Group Forming cases, the receivers/group members start listening to the Layer 2 ID/cast-type to receive traffic. Group participants may join a group passing the Layer 2 ID/cast-type to the communication stack in order to activate the reception. Group participants may reject a joining request or may drop from a group at any point in time.

Note: The Use Case may get cancelled, when essential receivers are not joining.

In the Group Dissolving phase it is mandatory to notify all vehicles about the end of the Use Case.

Additionally, three different ways a participant may be asked to join a group can function with these dynamic and pre-defined groups, which would depend on the cast-type and sending frequencies of the group members:

- A participant approaches a vehicle and requests information about group presence; if a group is present or not, it may join or could form a new group.
- A participant approaches a vehicle without knowing it is part of a group, and is requested to join the group explicitly.
- A participant approaches a vehicle in the group and receives information about group presence via broadcast.

8.2.1 Example with Group Forming 1

This Group Forming scheme was identified within the Use Case Group Start.

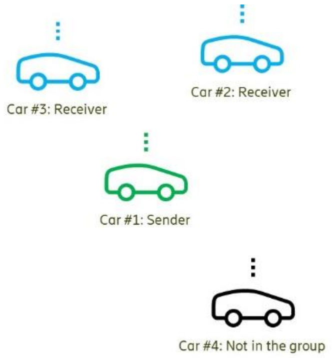

Figure 3: Scenario 1

Group Forming principle for Scenario 1:

1. Car#2 and #3 are the only vehicles interested in participating in the Use Case. The sender (Car#1 in Figure 3) wants to communicate to interested vehicles using PC5 Groupcast.
2. The sender (Car#1) allocates the Layer-2 ID and communicates the Layer 2 ID + cast-type for the group communication to participants, e.g. via PC5 Broadcast. Additional information (such as on application layer or from a defined registry) enables Car#2 and Car#3 to know for which kind of Use Case the group with the allocated Layer 2-ID is initiated by Car#1.
3. Receivers (Car#2, #3 in Figure 3) activate the reception of the groupcast (using the Groupcast Layer-2 ID).
4. Sender (Car#1) does not need to know the unicast Layer-2 IDs of the receivers.
5. Cars not interested (i.e. Car#4 in Figure 3) do not activate the reception and traffic is ignored on lower layers.
6. This Group Forming process can also accommodate late-joining vehicles.

8.2.2 Example with Group Forming 2

This Group Forming scheme was identified and studied within the Use Case Interactive VRU Crossing.

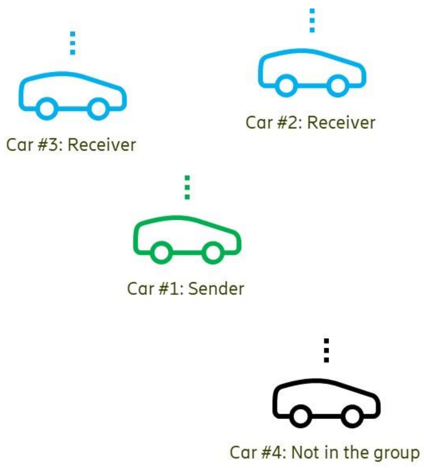

Figure 4: Scenario 2

Group forming principles for Scenario 2:

1. The sender (Car#1 in Figure 4) wants to communicate to Car#2 and #3 (in Figure 4).
2. The sender (Car#1) collects the broadcast Layer-2 IDs and application layer IDs of Car#2 and #3 from their periodic beacon message broadcasts:
    - The sender broadcasts its intent (i.e. desired manoeuvre or Use Case), desired participants (i.e. receivers), and a Layer-2 group ID + cast type at a fixed interval for a limited time (e.g. 5 seconds) or until application-layer responses have been received from all requested vehicles.
    - PC5 Broadcast is used here on purpose as the communication scheme. This way, all devices in proximity are made aware of an incoming potentially safety-relevant situation. With the example Interactive VRU Crossing, all vehicles should double-check the list of identified candidate vehicles. Other communication schemes can be used depending on the Use Case needs, e.g. via groupcast (Variant A) for higher reliability with an appropriate range-setting.
3. The receivers assess the desired manoeuvre, determine whether they will/can participate, and send a reliable unicast application-layer response to the sender. This way, their communication stays private between original sender (Car #1) and them.
4. The sender (Car#1) determines whether the manoeuvre is feasible with the participation of the vehicles that agreed to take part.
5. If the manoeuvre is determined to be feasible, subsequent communication for the manoeuvre will take place via groupcast communication with the originally communicated Groupcast Layer-2 ID.

Receivers should acknowledge the reception of the PHY Layer groupcast on the application layer.

8.3 Summary

Different Group Forming and addressing principles are identified during the work, leveraging different PC5 communication schemes. NR PC5 supports additional communication schemes beside PC5 Broadcast. Note that groups can be formed on Layer 2 and on Application Layer. Two (dynamic) application layer Group Forming typeswere identified during the work, more may be available. Additionally, other options may exist with pre-defined AL groups.

The three cast-types are beneficial to Complex Interactions and the combination of them can greatly benefit their implementation, especially to address different Use Case needs.

The different addressability, casting and Group Forming principles can enable centralised and decentralised groups to form.

The topics around group splitting and merging have not been evaluated within this work. The topic of ‘group coexistence’ has been considered by dynamically selecting groupcast Layer 2 IDs.

9 Conclusion and Next Steps

To finalise this work, a summary of the findings and future steps and recommendations will be given here.

9.1 Summary of Findings

- Firstly, Complex Interaction Use Cases were identified from the available Use Cases previously published. With this, their commonalities and difference upon inspection were identified and described.
- In the previous sections, three phases of Complex Interaction Use Cases were identified. Firstly, some sort of Use Case forming is required where the members, group leaders, and Use Cases are identified and determined. In the second phase the participants are executing the Use Case and finally in the third phase the Use Case is terminated. Different mechanisms enabling the establishment and implementation of the Use Cases were identified and their relation to the three phases were presented. Also, different possible solutions for the required mechanism were identified and briefly described.
- Some sort of Group Establishment, even if only between two communication partners, is required. This, however, also means there is no need for One-to-One group management structures, which only becomes important with three or more participants.
- The established mechanisms can cover many Use Cases with different initial requirements. It is, however, important that negotiation between participants and fallback systems take place effectively, regardless of environment and situational limitations. This will render the Use Cases truly effective, especially when the cancellation of the Use Case can be completely avoided.
- The identified mechanisms can be implemented for multiple Use Cases. Therefore, reuse of the mechanisms for Complex Interaction Use Cases is possible and the mechanisms can serve as building blocks to further describe and define new Use Cases with Complex Interactions and define specific implementations.
- Multiple technical solutions and steps to resolve the identified functional mechanisms required in an implementation were identified and presented in the document.
- There is a direct link between the number of data exchanges, the order of information exchanges and which data is communicated in which exchange. It is therefore important to define all these components together.
- The theoretical message sequence analysis of the three selected Use Cases have shown that a defined sequence of messages and defined steps for implementation need to be defined and standardised. Differing implementations would lead to unnecessary complexity and potentially cause incompatibilities between different OEMs.
- Many already existing data elements can implement complex interaction Use Cases. Only a few data elements or variations of them would need to be defined and standardised for realisation.
- The new NR PC5 unicast and groupcast communication links on layer 2 can increase efficiency and facilitate Group Forming and Use Case realisation. However, application layer acknowledgements will still be needed to ensure reliability on the higher layers when the L2 enablers cannot be used or where application acknowledgements are needed for high-risk situations.
- There is more work required in the domain of cooperative manoeuvres. Further Use Cases need to be evaluated and definitions of different terms surrounding the possible levels of cooperation need to be defined. This will be an important step to clarify the general understanding and expectations from the applications, as these topics are not covered in the Use Case descriptions.

9.2 Potential input to SDOs

The Work Item has identified multiple topics that will need to be reviewed and evaluated within Standard Defining Organizations (SDOs) to ensure the future interoperability of Complex Interactions.

- Definitions of different terms such as complexity and cooperation levels will be necessary to further refine and develop implementation profiles or user stories for such Use Cases. This will provide clarification for the ecosystem.
- Further work is needed to define the necessary exchanges and message exchange order for the Use Cases. Even though a Use Case can be implemented in different ways, these need to be agreed and defined, maybe by using some form of Use Case profile definitions. This way, a Use Case can be implemented in different manners and vehicles can identify if they can participate in a specific implementation or user story type. This can, for example, support different hardware and software generations within vehicles and be more future proof.
- The basic implementation steps undertaken for the analysis of Use Cases with Complex Interactions have demonstrated that more data and ID types, and different (potentially) dedicated messages are in some form

necessary to implement the Use Cases. Each Use Case might require different data elements, and a way to identify the sequence of information exchange is necessary to implement such Complex Interaction. Without tracking the sequence of exchanges, it is nearly impossible to verify in which Use Case stage the data is intended. Additionally, the potential of implementing identifiers to define a specific Use Case unmistakably identifies the planned use in the exchange.

- The different identified mechanisms can serve as modular 'building blocks' for the creation of new Use Cases. If these mechanisms are added together in specific sequences, many different broadcast or unicast Use Cases with varying vehicle densities, speeds and safety needs can be built and developed, while staying backwards compatible as much as possible. This can drastically reduce the risk of longer standardisation cycles and frequent updates to the V2X system, and it can accelerate the go-to-market time of new functions. These mechanisms can be defined as building blocks or tools for Use Case profile standardisation.

9.3 Future Activities

With the findings, different future potential activities around the topic of Complex Interactions were identified:

- The definition and the depth of the required implementations remain unclear to different stakeholders. Here, the line between implementation choices left to industry and topics which require standardisation also need to be clearly defined. This topic will need to be first clarified before larger-scale standardisation activity such as Use Case profile definition can be undertaken.
- There is no specific organisation that standardises these kinds of applications and profiles, as the range of areas covered is relatively broad and covers multiple stack layers. Suitable SDOs need to be identified, which are capable of executing this kind of activity. An example can be the current developments within ISO for the Use Case AVP and the work among different organisations on the topic. As such applications require identical implementations and user stories on all participating entities, it is crucial that the whole application implementation is standardised. It does not suffice to have available message and facility standards 5GAA could act as the orchestrator among all stakeholders to enable such activities. This can furthermore ensure globally unified functionality instead of relying on regional SDOs with varying implementations in different regions.
- With a few exceptions, the topics on Complex Interaction Use Cases were not covered in depth within standardisation activities. This means different processes and structures for the definitions are not yet defined. This will be required for future-proof developments and effective standardisation of such Use Cases.
- Further developments in interoperability, as one crucial aspect of the Use Cases, will require heavy cooperation between stakeholders. The same applies to the testing of the functions; processes and testing procedures will therefore also need to be defined for these Use Case types.
- Furthermore, a sustainable framework will be necessary to ensure a future-proof environment for V2X Use Cases. By using clear templates, defined structures for applications, definitions and plans for using messages, implementations of Use Cases, and considering functional safety and Public Key Infrastructures, the development of future Use Cases can be executed without additional overheads, which would be the case if each Use Case is approached individually.
- A systematic failure analysis for each Use Case is required and has not been conducted during the current work, as the evaluation was purely theoretical.