Dynamic and Flexible Platooning in Urban Areas

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Abstract

Platooning for trucks on highways has been largely investigated in several research projects. There, the platoons are used to be safe and efficient “road trains” of close following vehicles centrally managed by a platoon leader via V2X communications. Once such a platoon is formed, it is very stable and often restricted to one lane.

At the same time, Cooperative Adaptive Cruise Control (C-ACC) uses a distributed approach in which any vehicle can use V2X receptions to maintain a constant gap from the preceding one. In this sense, quasi-platoons composed by C-ACC vehicles became an option for more flexible platoons under urban conditions. Lioris et al. [1] therefore performed simulations to demonstrate the positive effects on throughput on urban roads when a C-ACC-platoon passes signalized intersections.

But platooning under urban conditions is more than just passing intersections in close distance, and it is much more dynamic and flexible compared to platooning on highways. First, opportunities for vehicles to build platoons have to be detected based on some local common criteria (e.g. similar destinations, acceleration capabilities, speed requirements). Secondly, while driving in a platoon, various dynamic situations have to be handled, like platoon splitting, recombining, breaking-up by conventional vehicles, urgent reactions to vulnerable road users, etc. Furthermore, the efficiency of urban platoons can be increased when platoon members and the infrastructure cooperate, e.g. in terms of adaptive traffic light control or cooperative sensing.

Within the EU H2020 project MAVEN (Managing Automated Vehicles Enhances Network, [2]), dynamic urban platooning is investigated, esp. in the light of hierarchical traffic management. How can infrastructure help to enhance traffic efficiency and safety in urban areas by also taking into account platoons? MAVEN is going to answer this question by performing traffic simulations and prototypic implementations.

This paper provides detailed information on the first steps taken in MAVEN related to flexible urban platooning. New approaches for dynamic platoon initialization, joining, leaving and splitting are discussed. The proposed communication protocols and the detailed logic for platoon members are presented. Furthermore, first results of simulations and prototypic implementations are shown.

Keywords: Urban Platooning, C-ACC, hierarchical traffic management, platoon split up, cooperative lane change

Introduction

Several research projects dealt or deal with platooning of trucks on highways. Platoons in this context are safe and efficient “road trains”, where a leading vehicle is followed by other vehicles in a very close distance. While the leading vehicle may be automated or still driving manually, the following vehicles are at least longitudinally automated to allow the close following. V2X technology is the key for such systems to work, as precise acceleration and braking information can be forwarded from the leading vehicle to the followers without the delays created by normal detection and interpretation algorithms of on-board sensors and sensor data fusions, and without the limitation of reacting to the direct predecessor only. Those systems are designed for stable driving for long distances, allowing fuel saving and less demand on drivers, possibly even replacing them during following. Newer approaches take into account that gaps have to be opened for other vehicles to merge in, but stability is still a key element.

In the European H2020 project MAVEN, one of the research topics is to bring platoons to arterial roads in urban areas, as close distance driving of cooperative automated vehicles (CAV) maximises throughput and efficiency of urban road networks. Especially at signalized intersections positive effects are easily comprehensible, e.g. when traffic lights turn green and all members of a platoon instantly start accelerating at the same time. MAVEN even goes one step ahead by following a hierarchical approach, where infrastructure also communicates with vehicles and negotiates traffic light phases with the demands of the traffic participants. By taking platoons into account, traffic lights may allow whole platoons to pass at green lights, further enhancing the efficiency of such signalized intersections.

Nevertheless, urban platooning is different compared to platooning on highways. While vehicles on highways share the same route for many kilometres, vehicles on urban roads only share the same route for a very limited time, e.g. passing a few intersections before separating again. Furthermore, compared to highway driving, urban driving on arterial roads is very flexible and dynamic. Vehicles change lane very often. Obstacles like parked vehicles or trucks stopped for loading appear on the road requiring a specific action like a lane change. In addition, vulnerable road users exist on the road sometimes requiring a fast reaction of single vehicles. This is also true for members of a platoon. Therefore, one of the key features of urban platooning needs to be flexibility.

In the past years, a new flexible possibility of close following has been researched in many projects: Cooperative Adaptive Cruise Control (C-ACC). According to [3] and [4], C-ACC, as next generation ACC system combining ACC behaviour with V2V communication, offers the ability of closer following of a vehicle, without the necessity to have a formal leader. In contrast to normal platooning, the follower is deciding on the appropriate distance/time-gap and the leading vehicle does not take any responsibility for the following vehicle(s). Therefore, C-ACC systems offer much more flexibility compared to platoons with a dedicated leader, as no coordinated membership registration at the leading vehicle is taking place. Vehicles can simply start and stop following at any time. On the contrary, C-ACC has several limitations. It offers longitudinal control only, and is designed neither for very close following reducing air drag nor for stability of larger platoons. To achieve this, C-ACC systems need to be enhanced, e.g. like done for stability in [5], or combined with other systems offering lateral automation and taking over steering control.

Due to the need of hierarchical traffic management influencing the platoon in MAVEN, it has been decided to follow a hybrid approach. On the one hand, the platooning action is based on C-ACC. Therefore all control actions (gap size, speed…) inside the platoon are performed on own responsibility. On the other hand, there is a

dedicated platoon leader responsible for the communication to the infrastructure. This enables the needed flexibility on the one hand, but still allows the benefits of a hierarchical approach with a dedicated contact point of a whole platoon.
In MAVEN, this platooning approach is currently prototypically implemented and tested, first in simulation, and later on by using DLR and HMETC test vehicles. Besides several tests on closed roads, it is planned to have a final version running on public roads in Braunschweig, Germany, in Q1/2019.
This paper presents a detailed overview of the approach, showing the platoon logic for each member, the communication aspects and an excerpt of the use cases investigated.

Urban Platooning Logic

The basis for the logic behind the urban platooning is a set of state machines, each serving a specific aspect of the platooning logic. In order to have a stable platoon at the end, it is very important that these state machines are implemented in all vehicles being part of the platoon in the same way. This is also true for the conditions used for state transitions, which need to be defined globally in order to reach a stable behaviour.

The state machines implemented are shown in Figure 1. Each of them has the following tasks: The basis for all actions is done in the main *platooning state machine* which shows the current platooning state of the vehicle. Besides, there is a platoon *forming state machine*, which is only active during platooning (i.e. when the platooning state machine is in the state “in a platoon”). Furthermore, there is the *message state machine* which is responsible for the frequencies each part of the platoon-related V2X messages are sent. Finally, there is the *distance state machine* which is responsible for managing the distance to the vehicle ahead or opening up a gap.
All of the state machines are explained in the following.

Platooning State Machine

The platooning state machine represents the overall state of the vehicle, so it describes whether the automated vehicle is currently not able to drive in a platoon, has the wish to create or join a platoon, is currently driving in a platoon or currently leaving one.
Normally, the vehicle should plan to drive in a platoon to gain the benefits of this kind of driving, like less waiting times on upcoming

intersections. Nevertheless, the vehicle might not be able to join a platoon (state: *"Not able")* due to various reasons: the needed subsystems may not be working or not getting the clearance for being active, or the driver has disengaged the platooning option.
Whenever this is not the case and the system starts running, the state *"Want to form"* is active. In this state, the vehicle announces that it is available for platooning by transmitting, via V2X, desired acceptable platoon characteristics, like the planned route on the upcoming intersections or the desired speed (Details can be found in Table 1 in the V2X communication section further down). Nevertheless, it is not related to any specific situation on the road. Instead, it is more a local general plan of the vehicle's automation.

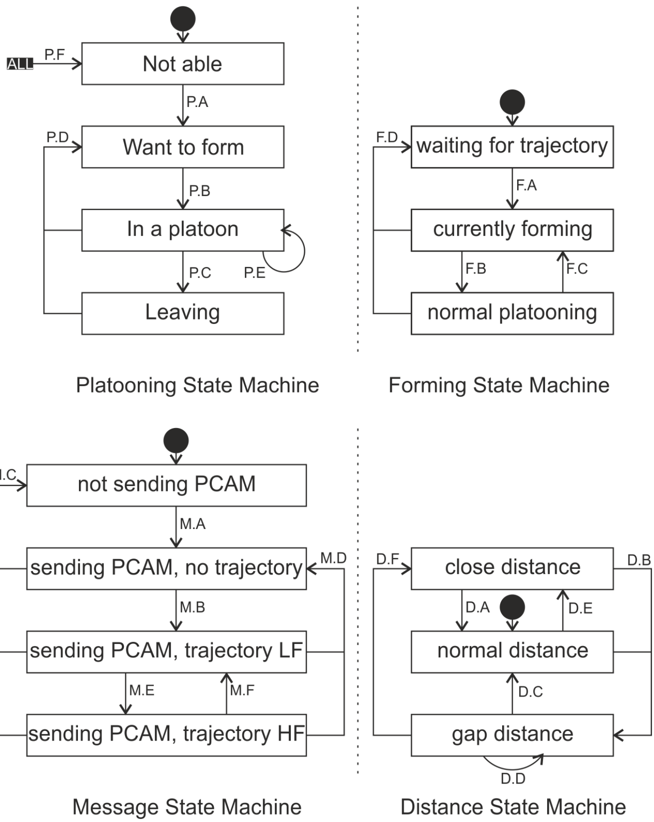

Figure 1: The four different state machines used for platooning

The platoon state machine stays in this state until a vehicle in front is detected to be close enough, transmitting matching acceptable platoon characteristics (i.e. which wants to drive the same route and with similar speed), and informing about intention to form a platoon, which makes this vehicle a potential follower. When this is the case, the follower directly switches to *"in a platoon"*.. Further details of the procedure of forming a platoon are available in the forming state machine, which is activated in the moment of getting into the state *"in a platoon"* and described further below. A predecessor (and therefore potential leader of the platoon) is switching to this state when a follower indicates the desire to follow. When the vehicle is in state *"in a platoon"* it still advertises the acceptable platoon characteristics like in state *"Want to form"*, but truncated by the boundaries of the platoon participants, in order to acquire further members. The current implementation does not foresee any limitation of the number of platoon members of a single platoon, as each follower is in control of the driving task on its own. Nevertheless, practically the number of followers will be limited in urban areas, as traffic lights may not guarantee green lights for all members of very long platoons, which in praxis will lead to a splitting up of the platoon into parts.
Whenever a vehicle wants to or needs to leave a platoon, it will switch to the state *"Leaving"* which indicates that it is not available for platooning anymore and therefore temporarily not able to form another platoon.

Forming State Machine
As said, the forming state machine is only active when the vehicle is in state "*in a platoon*", and therefore is kind of a sub-state machine of this. It describes the current state of the platoon forming procedure and consists of the states *"waiting for trajectory"*, *"currently forming"* and *"normal platooning"*. The state machine is initialized in the first state, where it waits for more detailed trajectory data of the leading vehicle. As long as this data is not received, the following vehicle is not able to drive in closer distance. Whenever this data is received, the forming process is started and the gap is reduced until the desired following distance is reached.

Message State Machine
As it will be explained in the next section, V2X communications for MAVEN platooning rely on two Cooperative Awareness Message

(CAM) extensions: the Extended legacy CAMs, and the Platooning CAMs (ECAMs and PCAMs in the following, respectively). In this context, the message state machine describes the content and transmission frequency of the PCAM. It basically consists of four states and is running all the time.
In normal driving outside of platoons and far away from other platoon forming candidates, the vehicle continuously broadcasts only ECAMs and hence is in state *"not sending PCAM"*. Whenever it is detected that there is another vehicle, which matches own desired platoon properties, approaching from behind and close more than a given threshold the vehicle is changing state to *"sending PCAM, no trajectory"*. By doing this, the vehicle starts transmitting basic platoon information needed by the follower to understand the predecessor's platoon forming intention. Whenever a vehicle behind informs about being *"in a platoon" state*, trajectory information needs to be included at low frequency (LF), resulting in a change to *"sending PCAM, trajectory LF"*. This state is the normal state while forming a platoon or driving in a platoon with followers. Nevertheless, in some cases it may be essential to receive trajectory data at a higher frequency (HF), e.g. when an emergency situation appears or when a fast reaction is required. To cope with such situations, the state *"sending PCAM, trajectory HF"* has been introduced.

Distance State Machine

The distance state machine describes the currently proposed distance to the vehicle in front and is active all the time. During normal driving outside of a platoon, the state "normal distance" is active. Whenever there is a situation requiring the opening of a gap in front (independent of driving in a platoon or not) the state changes to "gap distance". The criteria for opening a gap are shown in Figure 2. The transition is triggered whenever there is a vehicle on an adjacent lane

- With its tail within a given range from own tail to preceding tail (blue area in Figure 2) or its front within a given range from own front to preceding front (orange area in Figure 2),
- Which is driving in the range +/-10% of own velocity,
- Which is intending to change the lane, e.g. by a set indicator, by a known lane closure ahead or by other more sophisticated means which are currently under research.

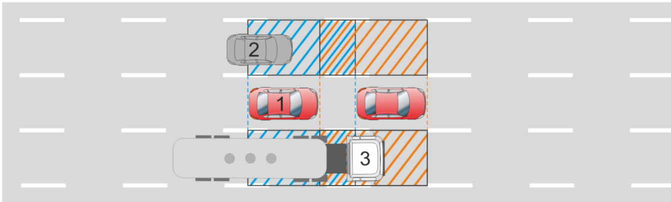

Figure 2: Ranges around vehicle 1 in which another vehicle is considered as candidate for a lane change to V1's lane. As the range is in relation to the tail of the other vehicle, V2 is not a candidate. The truck 3 is a candidate, because its front is in the orange area.

When the vehicle is currently starting to drive in a platoon with a forming state of "currently forming", the distance state machine changes to "close distance" in order to claim the goal of close following.

V2X Communication

In the design of V2X communications protocols and message set for MAVEN platooning, two aspects have been taken into account. From one hand, they must support the advanced functionalities of automated vehicles and platoons. From the other end, they must also ensure that cooperative legacy (not-automated) vehicles and existing C-ITS infrastructure (RSUs) keep receiving the necessary information available at preliminary V2X deployments. In MAVEN, this is accomplished by using ETSI ITS CAM message [6] extensions. The standard CAM is a periodic broadcast message including vehicle dynamic information (position, heading, speed, acceleration, etc.), as well as static attributes (width, length, vehicle type, etc.) and semi-static information for special vehicles (emergency vehicles, roadworks vehicles, etc.). The generation rate of CAMs varies dynamically in the range [1-10Hz] to capture sudden variations of vehicle dynamics while ensuring acceptable levels of radio channel load. In a first phase of V2X deployment (starting in 2019 [7]), the information received in standard CAMs will be used to implement Day1 applications such as detection of Traffic Jams ahead (at not-automated vehicles) or estimation of incoming traffic demands (at C-ITS infrastructure/RSUs). By defining MAVEN platooning messages as CAM extensions, backward compatibility is achieved: automated cars and MAVEN-capable infrastructure will be able to process the whole message including the extensions; legacy

vehicles and infrastructure will just discard the extensions, yet processing the rest of the message.
From a communication protocol point of view, the selection of CAM as a periodic broadcast message (instead of for example on-demand request/reply unicast messages) makes sense for MAVEN platooning. As explained in the previous sections, in MAVEN vehicle control (in a C-ACC fashion) and platoon management is executed independently at each individual vehicle following a common distributed protocol which uses the information locally available (on-board sensors as well as V2X receptions). Adopting dedicated alternative messages instead of recurring to small extensions to already deployed CAM messages would imply additional channel load (due to the presence of the lower layers' protocol headers) without necessarily providing increased reliability.

MAVEN CAM extensions for platooning
As explained above, V2X platoon messages must provide information suitable to detect platoon initialization chances as well as information about the changing platoon status and acceptable platoon characteristics. This information shall support decisions on whether an approaching vehicle could join a platoon or trigger traffic management reactions at the infrastructure side. Moreover, platoon vehicles need to exchange information to manage situations like leaving, merging, brake-up or termination. Most importantly, each platoon vehicle must transmit its dynamic data with enough frequency to allow followers driving at closer distances. For this purpose, two separate extended CAMs are used:

1) Extended CAM on SCH0 (Extended Legacy CAM or ECAM): carries information for CAVs to detect opportunities to initialize a platoon (e.g. based on same planned route, desired speed, etc.), as well platoon features reusable by the infrastructure (platoon ID, participants, etc.). As indicated in Figure 3, this information is contained in an optional special vehicle container called *MAVENAutomatedVehicleContainer*, and hence ensures backward compatibility with pre-existing Day1 systems in this channel.

2) Extended CAM on SCHx (Platooning CAM or PCAM): carries the needed information to manage and control platoons of MAVEN CAVs in a distributed manner. It is transmitted at a fixed higher

frequency [10-30Hz] and using a separate ITS channel not to overload Day1 systems on the SCH0 (the same approach is suggested in [8]). As mentioned before, its transmission is triggered during the platoon initialization phase. Then, the message is populated following the state machine logic. An *AutomatedVehicleContainerHighFrequency* is always transmitted to carry important information that CAVs consider for close following. The *AutomatedVehicleContainerLowFrequency* is included every x messages, mostly with information reflecting the state machine and used for distributed platoon management.

A more detailed description of the CAM extensions structure and their platoon-related content is reported in Figure 3 and tables 1 and 2.

	Data Field/Element	**Description**
MAVEN Automated Vehicle Container	*RouteAtIntersection*	Planned route at next intersection (in/out lane)
	IntersectionRoute	Planned route in terms of next intersections to cross
	DesiredSpeedRange	Desired min and max speed for driving in a platoon
	AccelerationCapability	Supported max positive and negative accelerations
	PlatoonId	Id of the platoon that the vehicle is currently in
	PlatoonParticipants	List of following vehicle IDs (tx by platoon leader only when approaching a cooperative intersection)
	desiredPlatoonSpeed	Speed the platoon desires to adopt (txd by platoon leader only when approaching a cooperative intersection)

Table 1: Platooning-related content of extended CAM on SCH0 (ECAM)

	Data Field/Element	Description
Automated Vehicle Container HighFreq.	*Heading*	Vehicle heading
	Speed	Vehicle speed
	LongitudinalAcceleration	Vehicle longitudinal acceleration
	LanePosition	Lane the vehicle is currently driving
	PlannedPath	Planned vehicle trajectory in terms of future positions and headings
	PlannedLane	Lane the vehicle plans to drive to
	EmergencyFlag	Indicates that an emergency situation is locally ongoing
Automated Vehicle Container LowFreq.	*PlatoonId*	Id of the Platoon that the vehicle is currently in
	PlatoonFollowers	List of following vehicle IDs
	PlatoonVehicleState	State of the platoon that the vehicle is currently in
	PlatoonFormingState	Forming state of the platoon that the vehicle is currently in
	PlatoonDistanceState	Distance state of the platoon that the vehicle is currently in
	PlannedPath	Planned vehicle trajectory in terms of future positions and headings

Table 2: Platooning-related content of extended CAM on SCHx (PCAM)

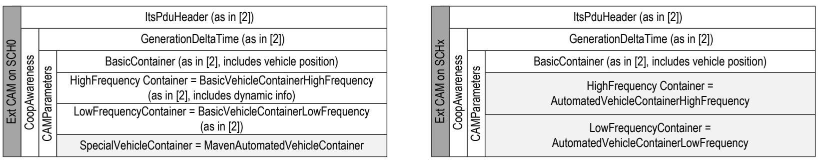

Figure 3: MAVEN extended CAMs structure

Use Case Examples

In MAVEN, urban platooning will be performed prototypically on public roads. Therefore, several tests have to be performed to assure correct behaviour of the platooning vehicles. For this purpose, different use cases have been formulated:

- Platoon initialisation: Two vehicles able to form a platoon meet on the road and agree on forming a platoon.

- Joining a platoon: Other vehicles able to form a platoon join an existing one at any position, i.e. in the front, becoming a new leader, in the middle or back of the platoon. This also covers the potential joining of two platoons.

- Travelling in a platoon: This use case describes the procedures while the platoon is driving and reacting to the surroundings and influences from traffic lights and other road users. This includes e.g. lane and speed changes of the platoon.

- Leaving a platoon: A part of the platoon (single vehicles or a section) is leaving the platoon due to different reasons. These can be planned reasons like following another route, or reactions to traffic light phases, but also emergency leavings in case of interrupted communication, system malfunction or sudden reaction to road situations.

- Platoon break-up: Reacting to the needs of unequipped vehicles is a key feature of urban platooning. Therefore, a platoon has always to make room for unequipped vehicles. In case unequipped vehicles want to merge to a lane used by a platoon, the platooning vehicles instantly have to react by opening up gaps.

- Platoon termination: A platoon can be terminated either when all vehicles leave the platoon on own decision or possibly when platoon termination is advised from the outside, e.g. by Road Side Units detecting complex situations ahead.

In the following, some covered example scenarios are given showing the behaviour of the platoon members and the state machines mentioned above.

Platoon initialisation/joining a platoon
One of the most frequent situations will occur when a vehicle able to join a platoon gets close to other vehicles with the same ability (platoon initialisation) or close to existing platoons (joining a platoon). As the speed variance in urban areas is lower than on highways, this will happen especially in the area of intersections, either when vehicles stop or brake due to traffic light phases or when vehicles turn to another road.
In general, the single vehicle (Vehicle 2 in Figure 3) will be in state “want to form”, while the platooning vehicles (1a, 1b and 1c) are in state “in a platoon”. As all platoon vehicles are transmitting ECAMs

and PCAMs all the time, vehicle 2 receives basic platoon information from them, especially from vehicle 1c. When all criteria are met (i.e. distance between vehicle 1c and 2 gets below a threshold, there is no car in between, and the route and speed information of the platoon is in line with those in vehicle 2), vehicle 2 changes its states to “in a platoon”. It starts sending PCAMs, including the platoon leader id (1a) and the indication that it has no followers. Nevertheless, vehicle 2 does not reduce the gap size as long as it does not receive a positive answer from the platoon members that they are able to include it as new member (it is “waiting for trajectory” from 1c). The new messages are received by at least some platoon members.

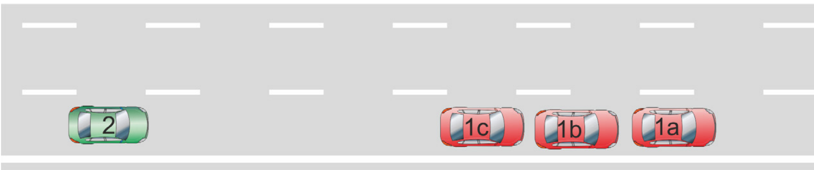

Figure 4: Initial situation of use case “joining a platoon”.

As all platoon members have the same criteria for platoons, the platoon members will add vehicle 2 to the platoon and therefore also to the list of followers. Each of these vehicles will reflect this in the transmitted PCAMs. In case one platoon member has not received the initial message, it will receive the changed PCAM and do the inclusion.
When the last vehicle in the platoon (1c) has agreed to the inclusion, it will start providing trajectory data in the PCAM. This trajectory data includes planned movements and therefore also reactions to the planned path of the vehicles ahead and the platoon leader. Vehicle 2 receives this trajectory data and can directly start to reduce the gap size. Its states change to “currently forming” and “close distance”. It will reach the tail of the platoon and continue driving as platoon member.

Travelling in a platoon and leaving
When travelling in a platoon, the platoon has to react to several situations occurring on the road. The standard behaviour will be to keep the platoon united whenever possible. In MAVEN, the number of platoon members provided with the ECAM to the cooperative

infrastructure will influence traffic signal phasing, so also the infrastructure will try to keep the platoon united as long as possible. This is also true when the infrastructure provides lane change advices in case one lane has denser traffic than the other. But of course, sometimes it is unavoidable to split the platoon. This can happen when traffic lights cannot allow all platoon members to pass the intersection or when there are slow or parking obstacles ahead on the lane and other vehicles on the adjacent lane available for passing (Figure 5).
Also other scenarios are possible, like platoon members who want to leave the platoon or have to do this due to emergency situations.
Independent of the reason (exception: platooning prohibited by the infrastructure in general), each vehicle has the ability to decide to leave the platoon on its own and the ability to choose the precise moment when this is needed. This is, as described, one of the key requirements for urban platooning.

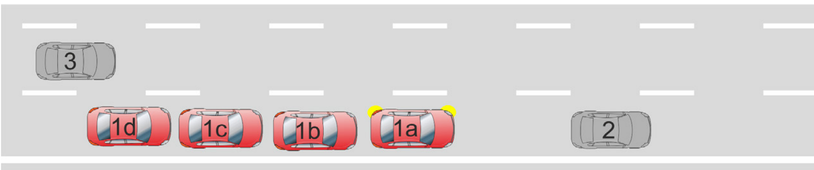

Figure 5: Platoon splitting due to slow vehicle 2 ahead and a vehicle on the adjacent lane.

When, e.g. as shown in Figure 5, vehicle 1a as platoon leader decides to change the lane, it may try to have an overview on the overall situation, but it will not be responsible for a safe lane change of all platoon members. Therefore, vehicle 1b has to decide whether it is safe to change the lane or not on its own. In the example, it agrees to follow and sets the indicator accordingly. In contrast, vehicle 1c decides that vehicle 3 is too close and that a lane change is not safe. Therefore, vehicle 1c is deciding not to follow the platoon any more. It will enlarge the gap, set the platoon leader id to its own id and provide a new planned trajectory without the lane change in the PCAM. This is received by the other vehicles. While 1a and 1b confirm the leaving by reducing the number of respective followers, vehicle 1d confirms by reflecting the new platoon leader id in its extended PCAMs. As result, the platoon is split into two. One is changing the lane, the other is staying on the lane until vehicle 3 has passed.

Platoon break-up

As mentioned, urban platooning needs to be very flexible and reactive to vehicles without the ability of wireless communication or cooperative behaviour. Therefore, platoon break-up is one of the most common scenarios. Figure 6 shows an example of such a situation. As shown, there is a non-cooperative vehicle 2 which wants to change to the right lane, where a platoon is currently driving. As explained in Figure 2, in the distance state machine section, only at vehicle 1c the condition is met to open a gap for vehicle 2. It will decelerate, but stay a platoon member.

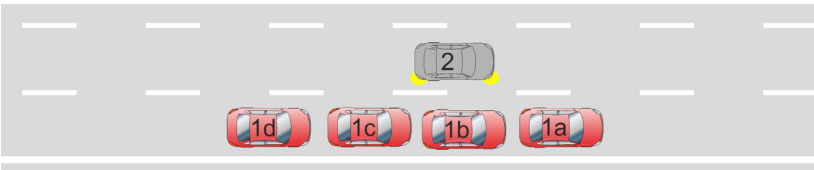

Figure 6: Platoon break-up due to merging vehicle.

After a while, the gap is large enough and vehicle 2 changes lane between vehicles 1b and 1c. This is detected by 1c, which now recognizes that there is a non-platooning vehicle in between the platoon. Vehicle 1c therefore will directly uncouple from the platoon by changing its platoon leader id to the own id. This is understood by the other vehicles by PCAM receptions. Similar to the former example, 1a and 1b confirm the leaving by reducing the number of respective followers. Vehicle 1d confirms by reflecting the new platoon leader id in its PCAMs. Once again, the platoon is split into two.

The crucial part of this use case, nevertheless, is the detection of the intention of vehicle 2 to change the lane. In some situations the intention is clear, e.g. when two lanes merge into one, but in others it is difficult. Radar, lidar or ultrasonic sensors monitoring the side of the vehicles may detect that the vehicle is getting closer, but this will be very late. Cameras may detect set indicators, but due to close following in the platoon this can also be difficult or even unachievable when the camera is mounted near the interior rear view mirror as normal. In MAVEN, the detection of lane change intentions is therefore planned to be done assisted by cooperative sensing, where other vehicles or the infrastructure share sensor data, making detection simpler. In addition, first scenarios will keep larger distances to test the capabilities of the mounted sensors.

Summary and outlook

This paper has presented why platooning on arterial roads in urban areas needs to be very flexible and dynamic. An approach has been sketched, showing how urban platooning can work in real life, including state machine logics, communication details and how both parts are integrated to solve this task in relevant situations.
For now, the proposed research has only been tested in low fidelity simulations, but showed already promising results. This includes several scenarios exceeding the scope of this paper, where e.g. more interacting vehicles, packet loss, or changing behaviour of vehicles have been investigated, esp. in terms of oscillating states and stability. Further details can be found in the public MAVEN deliverable 3.1 available soon.
In MAVEN, platooning is not only done in simulation. The algorithms will be tuned and further developed, and then implemented into real test vehicles owned by DLR and HMETC: One Volkswagen eGolf, one Volkswagen Passat GTE and one Hyundai Ioniq. All three vehicles are equipped with the needed hardware, including sensors, actuators and communication technology.
Several tests will be performed on different closed test tracks, e.g. in Braunschweig, Griesheim (close to Frankfurt) and Edemissen (close to Peine) in Germany.
When all tests have been performed, the final setup is going to be tested in Q1/2019 on public roads in Braunschweig, which are part of the AIM reference track [9].

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