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Looking into the Path Future: Extending CAMs for Cooperative Event Handling

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***Abstract*—Cooperative driving is a key enabler for safe and efficient driving. The European Telecommunications Standards Institute (ETSI) published standards for message dissemination and packet formats for continuous status notification, i.e., Cooperative Awareness Message (CAM), and asynchronous event notification, i.e., Decentralized Environmental Notification Message (DENM). Cooperative Intelligent Transportation Systems (C-ITS), such as platooning, rely on these messages that are exchanged between vehicles and infrastructure. However, CAM and DENM do not target cooperativeness: future paths can not be shared. Therefore, in this paper we present a modified CAM structure that allows a vehicle to indicate its own future trajectory over a variable spatial and temporal horizon. It may be used in combination with DENM to cooperatively handle events and limiting their impact. The presented approach is tested in simulation using Omnet++ and Simulation of Urban Mobility (SUMO) considering an IEEE 802.11p network.**

***Index Terms*—C-ITS, CAM, DENM, platooning, IEEE 802.11p, Omnet++, SUMO**

I. INTRODUCTION

Cooperativeness in the field of Intelligent Transportation Services (C-ITS) is mainly linked with sensing and maneuvering. Cooperative sensing targets a current situation: it allows to increase the sensors' field of view by exchanging gathered information. By the possible elimination of blind spots and occlusion, it may increase the robustness of the environmental perception. In scenarios where lane changes of surrounding vehicles are involved, sensors reach their limits [1]. There, cooperative maneuvering increases the field of view even further: by notifying or sometimes even negotiating maneuvers, problematic situations may be avoided. Some requirements of certain C-ITS applications, e.g., platooning, are even more critical: due to shorter inter-vehicle distances, compared to regular driving, less time for perception and reaction is available. Alam et al. [2] show that two identical vehicles are able to maintain a distance of $1.2\,\mathrm{m}$ which enables to exploit fuel saving potentials.

Generally, platoons are designed to be string stable, i.e., disturbances are not amplified when propagating downstream along the vehicle string [3]. To minimize the inter-vehicle distance, wireless communication is considered, although it comes along with delays that may impact string stability [4]. Delays are mostly caused by channel congestion that may be anticipated [5], making it important to reduce communication to the essentials [6]. Nowadays, in vehicular ad-hoc networks, communication mostly relies on the IEEE 802.11p standard. Message generation and formats are standardized by the European Telecommunications Standards (ETSI): status information is spread continuously using Cooperative Awareness Messages (CAMs) [7]. Once necessary, Decentralized Environmental Notification Messages (DENMs) [8] inform about events. These standards will reach soon the mass market: in 2019 Volkswagen AG announced that the Golf Mk8 will be equipped with vehicle-to-everything (V2X) technology [9].

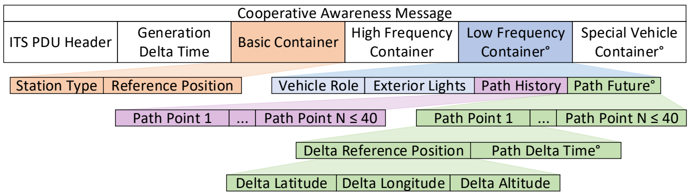


Fig. 1: Cooperative Awareness Message (CAM) structure according to [7], extended by *Path Future*. Optional fields are marked with an appended degree symbol (°).

However, string stability allows collision-free driving only under normal operation. Also platoons are prone to accidents: these are mostly related to cut-ins from surrounding traffic and rear-end collision [10]. Reasons for the latter may be technical failures in hard- and software, external factors (e.g., road conditions), and human failure, as not every platoon is considered to be fully automated [11]. This increases the importance of "good" driver behavior, especially for leading vehicles, that may be used to introduce a trust-based platoon service recommendation scheme that helps users to avoid choosing "bad" platoon head vehicles [12].

Contrary to existing work in the field of collision avoidance based on string stability within platoons, we go one step further and address the question: *how can we handle and limit the impact of events within a platoon running outside the bounds of normal operation*, i.e., where string stability is not sufficient for safety anymore? For that purpose, we *extend the current CAM structure enabling cooperativeness by notifying future trajectories and taking advantage of it*.

To do so, in Section II we shortly recap the concept of information dissemination using CAM and DENM. Afterwards, Section III proposes the CAM extension and compares its payload size to the existing standard. In Section IV we show how to make use of the proposed extension: we explain the handling of an event, notified by a DENM, to limit the damage for an accident within a platoon. Both CAM extension and event handling are simulated in Section V using Omnet++ and Simulation of Urban Mobility (SUMO). Finally, we discuss the results and conclude the work in Section VI.

II. V2X INFORMATION DISSEMINATION

Traffic participants and infrastructure need to notify their presence, share their states, and proclaim events. In the following, we introduce three services needed for operation within a platoon.

Cooperative Awareness Service: To gain knowledge of the environment, ITS-stations (ITS-S), i.e., vehicles and also Road Side Units, send so-called Cooperative Awareness Messages (CAMs) [7]. Their creation is periodically, but the period may shift within a generation interval of $[0.1\,\mathrm{s}$ - $1.0\,\mathrm{s}]$. In case the generating unit is a vehicle, the generation of a message depends on the difference between current values and values included in the last message. Differences in heading $(4°)$, in position $(4\,\mathrm{m})$, and in velocity $(0.5\,\mathrm{m\,s^{-1}})$ are able to trigger the CAM generation. As shown in Fig. 1, each CAM includes *ITS PDU Header*, *Generation Delta Time*, *Basic Container*, and *High Frequency Container*. Within the latter, some fields are optional. Optional fields are marked with an appended degree symbol (°). Note that the green colored fields are newly introduced in this paper and are not included in [7]. While the *Special Vehicle Container* is totally optional, the *Low Frequency Container* (*LFC*) shall be included if $0.5\,\mathrm{s}$ or more elapsed since the last CAM with *LFC*. The *LFC* contains the *Path History* representing the vehicle's recent movement over a certain time or distance. According to ETSI TS 102 894-2 [13], the *Path History* may include up to 40 *Path Points*. Its length depends on the trajectory, driving conditions, and speed of the vehicle [14]. The first entry is the point closest to the vehicle representing an offset in position (latitude, longitude, altitude) to the *Reference Position* that is transmitted within the *Basic Container*. Other points are sorted ascending according to their distance to the *Reference Position*. In contrast to the first entry, following points represent an offset position to the previous point. Optionally, each *Path Point* may also contain a *Path Delta Time*, stating the time difference between two *Path Points*.

Decentralized Environmental Notification Service: In contrast to a CAM, a Decentralized Environmental Notification Message (DENM) is used to announce events that may have an impact on road safety or traffic condition [8]. As CAMs, also DENMs consists of compulsory and optional fields. The DENM structure is illustrated in Fig. 2 where optional fields are marked with an appended degree symbol (°). Using the *Situation Container* it is possible to address different event types, that may be location persistent (e.g., dangerous curve) or may change its position (e.g., emergency vehicle approaching). Within the *Management Container* position and duration need to be specified. They may change over space

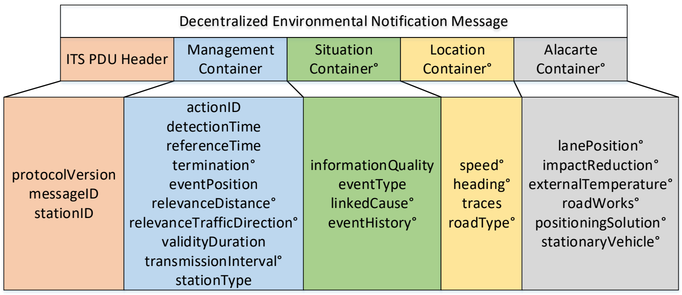


Fig. 2: Decentralized Environmental Notification Message (DENM) structure according to [8]. Optional fields are marked with an appended degree symbol (°).

and time. To address this, besides the announcements of new events, events may be updated, canceled (i.e., cancellation of an event by the originating ITS-S), or negated (i.e., cancellation of an event by any other ITS-S). Of course, the trigger conditions depend on the event specified using the field *Event Type*. An *Event Type* consist of a *Cause Code* (*CC*) providing general information, e.g., 12 indicates human is on the road, and a *Sub Cause Code* (*SCC*) giving further details. For example, *CC* 12 and *SCC* 1 means children on the road. The standardization for *CC* and *SCC* in DENM can be found in [15].

Platooning Service: The above mentioned services do not include the management of a platoon, i.e., creation, maintenance, and dissolution. To do so, we use the decentralized approach presented in [6]. The approach accounts for network properties, road conditions, traffic scenarios, and vehicle heterogeneity. However, as other platoon management approaches [16] [17], it does not account emergency handling. To do so, in the following section we propose an extension for CAM that enables notification of future trajectories and thus, cooperation.

III. PATH FUTURE

By *Path Future* we understand a data structure that is used by a vehicle to indicate future trajectories. This allows vehicles to plan their trajectories according to other vehicles trajectories and creates a base for maneuver negotiation. The implementation of *Path Future* is inspired by the already available *Path History*, standardized in [13]. We propose that *Path Future* is optional, i.e., it is only included into the CAM once extraordinary trajectories are scheduled. Extraordinary trajectories are all movements that differ from normal following of the predecessor using the platoon controller to maintain a defined inter-vehicle distance. As the *Path History*, the *Path Future* is part of the *LFC* and consists of a sequence of *Path Points* (see Fig. 1). A *Path Point* indicates the distance (latitude, longitude, altitude) from a predefined reference position and it contains an optional delta time (*Path Delta Time*) with a $10\,\mathrm{ms}$ resolution. This delta time determines the time difference to the previous point of the sequence. Within the sequence, *Path Points* are sorted chronologically, meaning the closest point is the first entry. For the first entry, the delta time refers to the message generation time. The delta time does not need to be unavoidably the same for every *Path Point*. It makes

TABLE I: Payload of CAM dependent on used fields.

CAM type	transmission	payload in bytes	size factor
A (min. required fields)	[0.1 - 1.0]s	41	0.1
B (A plus *LFC* with max. *Path History*)	$\geq 0.5\,\mathrm{s}$	389	1.0
C (B plus max. *Path Future*)	event triggered	734	1.9
D (A plus *LFC* with max. *Path Future*)	event triggered	389	1.0

perfect sense to select it dynamically: e.g., in the near future *Path Points* may be selected closer in time, continuously increasing the *Path Delta Time* for points that lie further in the future. Additionally, driving scenarios may impact delta time and horizon: while driving close to or in critical areas, e.g., highway entries/exits, a higher density could be applied. In contrast to that, high speed driving would benefit from a bigger horizon. Thus, the number of points within a *Path Future* may vary. As for the *Path History*, at most 40 points are used. The resulting new CAM with the modified *LFC* is illustrated in Figure 1.

Using optional fields increases the CAM size. Due to many optional fields, CAM sizes are very diverse [14]. The size of *Path History* and *Path Future* depend on the number of used points and if *Path Delta Time* is included. Table I compares the payload size of four out of many possible CAM compositions: CAM type A indicates the minimum size, avoiding all optional fields (see Fig. 1). It consists of *ITS PDU Header*, *Generation Delta Time*, *Basic Container*, and the mandatory fields of *High Frequency Container*. Once a *Path History* is used, a *LFC* is added containing also *Vehicle Role* and *Exterior Lights*. CAM type B assumes the maximum number of *Path Points*, which is 40, and *Path Delta Time* for each point. Once necessary, the *LFC* can be equipped additionally with a *Path Future*: CAM type C considers *Path Delta Time* for each of the 40 (maximum) *Path Points* for both *Path History* and *Path Future*. Assuming a network is able to deal with the load introduced by CAMs of type A and B, the impact of *Path Future* on the network load is limited. CAMs of type C are event triggered and due to the transmission interval of type B not sent more often than every $0.5\,\mathrm{s}$: there, in comparison to type B, the size factor is less than two. To relief the network, CAMs of type D instead of type C may be used: replacing *Path History* by *Path Future* does not increase the payload. Note that the indicated bytes are payload only: certificates or overhead caused by any other protocol, e.g., Basic Transport Protocol, GeoNetworking, 802.11p, etc., are not included.

IV. EVENT HANDLING WITHIN PLATOONS

Vehicles receiving information over Decentralized Environmental Notification Service may need to initiate event-dependent actions, called event handling. If additionally the vehicle is platooned, a Platooning Service is running simultaneously, managing the platoon and controlling the inter-vehicle distance to its predecessor. Events may appear at arbitrary time, number, type, and order: thus, requiring coordinated, ranked processing.

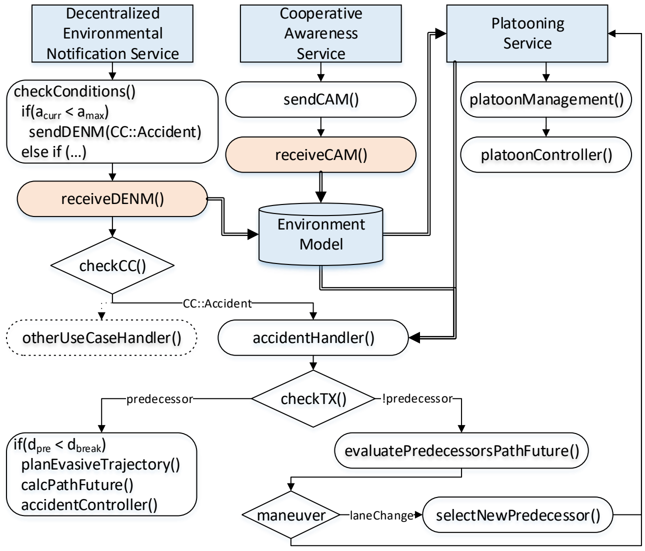


Fig. 3: Exploiting *Path Future*: cooperative event handling within a platoon where each vehicle is running Decentralized Environmental Notification Service, Cooperative Awareness Service and Platooning Service.

Due to human or technical failure, it may occur that one of the platooned vehicles crashes. In case the crashed vehicle is not the tail, following vehicles start to brake one after the other, as inter-vehicle distance, speed, and acceleration of the predecessor(s) decrease. The arising deceleration is above the assumed limits for controlling the platoon. Even though string stability is guaranteed, higher deceleration than expected cause further collisions. To avoid a collision, following vehicles could evade, e.g., by performing a lane change. This may not always be possible and contains a certain risk, as the time might not be sufficient, or other traffic participants block the neighboring lane. Therefore, it is important that only vehicles that would collide with its predecessor try to perform a lane change: for example, a vehicle that knows that its predecessor performs a lane change, may find enough space to brake safely. Drivers are not responsible to perform those actions: usually, while platooning, drivers of following vehicles do not need to be focused. Even then, the inter-vehicle distance is often too small to account for human reaction time. Therefore, this emergency case needs to be automated. To do so, we propose an architecture as depicted in Fig. 3. It allows event handling in platoons with the example of an occurred accident: while data flow is illustrated with double lined arrows in the corresponding direction, single arrows represent the program flow within services (rectangular box) over executed functionality (rounded box) and choices (diamond box).

Using the Cooperative Awareness Service, a vehicle sends own and receives other vehicles' CAM messages that allows to build and update an environment model. The latter may be extended by information provided by DENM messages. Information from the model may be used for the Platooning

Service and on specific events.

On the reception of a DENM, dependent on the *Cause Code* (*CC*), the appropriate use case handler needs to take over.

Once *CC* of type *Accident* (*CC::Accident*) is received, the vehicle checks who is the originator of the message, and with the knowledge from the Platooning Service its platoon affiliation and position within the platoon. In case the originator is

a) the predecessor: the vehicle compares the current inter-vehicle and the required braking distance on basis of data from the environment model. In case safe stopping is still guaranteed, the platoon controller is able to stop the vehicle in time. Else, an alternative has to be found. To avoid a crash, an evasive maneuver needs to be planned in case the current traffic situation allows, e.g., the neighboring lane is free. To inform other vehicles about the resulting trajectory, the *Path Future* is determined and sent within the next CAM. After that, the accident controller is activated, resulting in a suspended platoon controller.

b) not the predecessor: stored information from the environment model and from the Platooning Service, is used to determine what happens platoon-upstream. If available, predecessor's *Path Future* is evaluated and maneuvers extracted. In case the predecessor changes lane, a new predecessor is selected, i.e., next vehicle platoon-upstream. Due to the lane change and the modification, the platoon controller may be capable of stopping the vehicle safely on the same lane. On the next reception of DENM with *CC::Accident*, that may be resent from the originating ITS-S or forwarded by another ITS-S (e.g., predecessor), the accident handler is restarted.

As a result, lane changes are only performed once really needed, limiting the risk of interactions with other traffic participants. Further, the network is not unnecessarily loaded ensuring that other messages can be received reliably: vehicles that do not need to plan an evasive trajectory, do not need to send a CAM containing *Path Future* (type C or D in Table I). Once the platoon controller is sufficient, CAMs of type A can be sent, exploiting the size factor. Above on that, the presented approach forces a head to tail decision-making process enabling fast reaction: time is very limited in emergency cases. Thus, evading maneuvers are not neglected but notified. This keeps communication delays to a minimum.

V. SIMULATION

To validate and analyze the presented approach, a simulation with a platoon consisting of 4 trucks is performed. We do not assume blocking of the neighboring lane by non platooned vehicles. To do so, we use the simulation environment Omnet++ together with Artery [18], extended as described in [6] and applying also its control strategy. In combination with Simulation of Urban Mobility (SUMO), this enables a realistic road traffic simulation considering network and communication protocol properties related to IEEE 802.11p.

We assume homogeneous trucks, each having a length of $16.5\,\mathrm{m}$ and driving at an inter-vehicle distance of $10\,\mathrm{m}$. All vehicles run the services described in the previous section

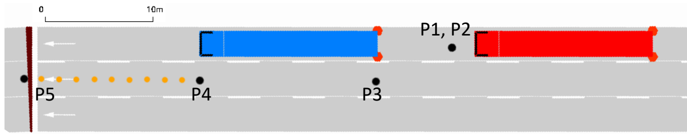


Fig. 4: Five pillar points (P1-P5) for planning the evasive maneuver for the red vehicle. Auxiliary points (orange) are added between P4 and P5 to avoid oscillations.

and illustrated in Fig. 3. In the following we focus on its realization.

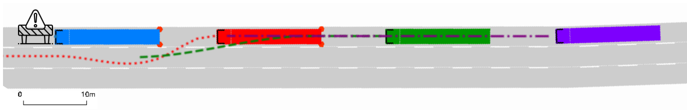
a) Evasive Trajectory Planning: To calculate simple evasive trajectory, a common approach using cubic splines is applied. Note that the evasion approach is for realizing simulation only. In real world examples more mature approaches should be used.

As shown in Fig. 4, we define five pillar points. The first point P1, is the position of the vehicle that needs to evade (red) considering measurement time and system's reaction time. It can be estimated using the last measurement, the time elapsed since then, system's reaction time, current velocity, acceleration, and heading information. P2 is shifted minimally in driving direction compared to P1. This allows a smooth start of the trajectory. P3 is the target that needs to be reached such that a collision (with the blue vehicle) is avoided. It can be calculated considering the width of both vehicles, a safety margin, and the left back corner of the predecessor. P4 is similar to P3, but lays in the center of the neighboring lane, normal to the left front corner of the predecessor. Finally, P5 is the elongation of P4 with predecessor's vehicle length. Minimizing overshooting after the lane change is necessary to avoid swinging off the lane and affecting other lanes or getting of the track: both is dangerous. Thus, nine auxiliary points (orange) are added by linear interpolation between P4 and P5.

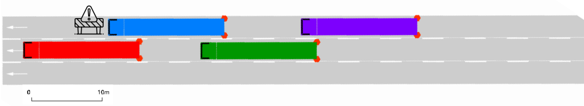
b) Path Future Calculation: According to the evasive trajectory, and the current vehicle state, a braking path is calculated. Using the spline, future way points are generated till stand still with a delta time of $0.1\,\mathrm{s}$. These way points are shared using the *Path Future* extension in CAM. Note, that till now all calculations were performed in a local coordinate system: resulting way points need to be transformed to the global coordinate system. To do so, up to 40 way points are converted to the global coordinate system and their offset to the current delta reference position (latitude, longitude, altitude) is calculated. Together with the *Path Delta Time*, they are part of the next CAM. With continuous duration, the *Path Future* becomes "shorter" or may even change. Thus, it gets updated with every *LFC* appended to the CAM.

c) Accident Controller: It tries to follow as accurate as possible the calculated evasive trajectory. This controller is prioritized due to the emergency situation and other running controllers such as the platoon controller get suspended.

d) Path Future Evaluation: The received *Path Future* of other vehicles can be integrated in the environment model: this allows to better estimate where vehicles may be in the future. Still, the *Path Future* does not contain any information about



(a) Moment of accident and head to tail decision-making: the platoon leader (blue) crashes and sends a DENM with *CC::Accident*. Followers plan and notify their trajectories using CAMs extended by *Path Future*.



(b) Stand still: all platoon followers (red, green, purple) are able to stop without causing further accidents.

Fig. 5: Handling of an accident using *Path Future*.

the type of maneuver. This information needs to be extracted from the *Path Future*. In case of a lane change, additional road and lane information can be used.

As shown in Fig. 5a, the leader (blue) crashes and consequently, triggers a DENM with *CC::Accident*, processed by following vehicles. The inter-vehicle distance of the first follower (red) is not sufficient to stop safely while staying on its lane. Thus, an evading trajectory, marked with red dots, is planned and shared using the *Path Future*. Due to the advertised lane change of the red truck, the second follower (green) changes its predecessor to the leading vehicle. The resulting, new inter-vehicle distance is still not sufficient to stop the truck in time. Again, as described above, an evading maneuver is planned and advertised (dashed line). Due to the lane change of both preceding vehicles of the purple truck, its new predecessor becomes the leader. In this case, the inter-vehicle distance is sufficient to stop in time (dotted dashed line). Fig. 5b shows the position of all vehicles after the event handling, i.e., when all vehicles stopped.

VI. Conclusion

An extension of the CAM standard ETSI EN 302 637-2 with *Path Future* was proposed that allows a vehicle to indicate its own future trajectory over a variable spatial and temporal horizon via V2X. It can serve as a basis for cooperative maneuvers. Together with DENM, *Path Future* can be used to improve hazardous situations. The modification leads to increased CAM size, but this can be compensated by proper CAM composition by substituting *Path History* by *Path Future* if needed. If both *Path History* and *Path Future* are used, the resulting CAM size increases by a factor of 1.9. Since *Path Future* is event triggered it does not impact network load in normal operation. The proposed CAM modification has been validated in detailed network simulation within a platoon scenario. There, even if string stability is guaranteed, accidents may occur due to various reasons. It was shown that with proper event handling the impact of an accident can be at least mitigated or in best case avoided. By planning and notifying future trajectories, further accidents of following vehicles can be prevented. Additionally, evasive maneuvers that may pose a hazard to adjacent lanes are reduced, i.e., only performed once really necessary. Further work remains in exploiting *Path Future* in more complex scenarios where negotiation of maneuvers becomes necessary.

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