An ETSI ITS-Compliant Formation Protocol to Support Long Heterogeneous Platoons

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***Abstract*—As penetration of autonomous technology grows, vehicular platooning also becomes a reality with clear benefits on efficiency and traffic management. One can consider that platoons may grow to arbitrary lengths, limited solely by the ability of achieving reliable end-to-end communication. We introduce the Long Heterogeneous Platoon (LHP) protocol, meant to handle very long platoons composed of vehicles with different characteristics and facilities. It creates autonomous sub-units, sub-platoons, that facilitate platoon maneuvers and internal communication. Coordination is achieved by newly proposed ETSI ITS-compliant messages or containers; a key message is the Platoon Management Message. In this paper we describe the platoon formation and subplatoon creation procedures of the LHP protocol.**

***Index Terms*—ETSI ITS, Platooning, CAM, LHP protocol**

I. Introduction

Vehicles are set to be equipped with wireless connectivity in the near future, enabling cooperation towards common goals [1]. In that context, platoons are sets of vehicles that act as a single entity, allowing for improved safety, fuel economy, and passenger comfort. With the advent of autonomous vehicles, platoons can grow arbitrarily long. A major challenge is to safely and efficiently manage a platoon as it grows, as the time required to propagate information from one end to another grows proportionally and restricts the number of member-vehicles [2], [3]. It adds to this that platoons may be composed of heterogeneous types of vehicles (such as trailers, passenger vehicles, etc.), a reality that needs to be considered when creating and managing the platoon and when accepting new members.

We propose the **Long Heterogeneous Platoon (LHP)** protocol to create platoons of arbitrary length and vehicle types and enabling an end-to-end communication network to support advanced applications. We do so by proposing, for each feature:

- **Long:** a platoon organization composed of sub-platoons to manage platoon maneuvers as well as structuring the platoon communication network;
- **Heterogeneous:** a Platoon Management Message (`PMM`) for platoon initiators, members and joiners to describe their facilities (e.g., vehicle characteristics, communication devices).

This work was supported by National Funds through FCT/MCTES (Portuguese Foundation for Science and Technology), within the CISTER Research Unit (UIDP/UIDB/04234/2020); by the European Regional Development Fund (ERDF) through the Operational Competitiveness Programme and Internationalization (COMPETE 2020) under the PT2020 Partnership Agreement and the Portuguese Foundation for Science and Technology (FCT) and the Portuguese National Innovation Agency (ANI), under the CMU Portugal partnership, within project POCI-01-0247-FEDER-045912 (FLOYD); and by ERDF through the Norte Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, within project NORTE-01-0145-FEDER-000062 (RETINA).

We detail the information-sharing structures required for these various functionalities. ETSI ITS standards define a number of message formats that can easily be extended to support our protocol. Seminal works on platooning protocols leveraging V2X links include [4], that addresses the *Join* operation. Recent work includes L-Platooning [2], a protocol that aims to provide constant inter-vehicle distance regardless of platoon size and puts forward the concept of virtual leader (VL) to extend the coverage of the platoon leader. Under ENSEMBLE [5], a protocol and CAM container to support platoon formation have been proposed, but vehicle heterogeneity is not extensively considered in platoon management (e.g., joining decisions).

Being a work-in-progress, we present the overall goals of the LHP protocol (Sec. II) and describe the initial components of the protocol, notably the platoon formation procedure (Sec. III) and sub-platoon formation (Sec. IV). Other components and performance analyses are to be reported in subsequent publications.

II. The LHP Protocol

The goal of the LHP protocol is to mitigate the long platoon response to complex maneuvering operations. These include: (i) platoon formation; (ii) internal platoon operations, such as *leave* and *split*; (iii) maneuvers involving the platoon and non-platoon vehicles, such as *join*, and *cut-in* requests (the case of a non-platoon vehicle that wishes to cross the platoon transversely); (iv) maneuvers involving platoons, such as *merge*.

Its key characteristics are: (i) handling of arbitrarily long platoons; and (ii) handling of heterogeneous vehicles (different facilities). Being arbitrarily long means that the platoon may become so large that end-to-end platoon behavior, particularly when performing maneuvers (e.g., lane change), becomes affected by the long delay between Leader (front vehicle) and the back of the platoon. Experimental work will allow identifying the platoon size at which significant behavior degradation is observed due to message delay.

To achieve the first point, the proposed protocol breaks down a long platoon into sub-platoons managed by a Virtual Leader (VL). This creates an organization that will be used simultaneously for management of the physical platoon as well as a structure for the platoon internal communications network. The VL should have sufficient resources to support its own members for an adequate length and the whole platoon will not be imposed on the overhead of re-selecting the VLs.

To achieve the second point, and support the first one, we propose a set of messages that enable vehicles to exchange various elements such as maximum speed, dimensions,

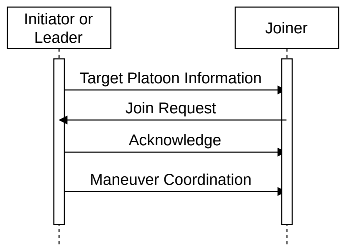

Fig. 1: Sequence diagram of platoon formation procedure.

communication capabilities, load type, engine type, autonomy type, among others. This information is used by both platoon leader and potential joiner to decide whether it is in their interest to accept a new member or join a particular platoon. We describe in the next section the platoon formation procedure.

III. Platoon Formation Procedure

We propose a long-platoon formation algorithm that starts with a single vehicle and has the capability to gradually set a very large platoon in highway scenarios. The vehicles that take this initiative are called *Initiators*. A potential reason for a vehicle to take this initiative may be the existence of a credit system, e.g. one that allows the vehicle operator to pay inferior tolls. Surrounding CAVs hear this advertisement and decide whether to join – we refer to those as (Potential) Joiners. We consider single vehicles for now as the merge of multiple platoons is considered a separate operation (*merge*), to be discussed at a later stage.

The platoon formation procedure is as follows (also in Fig. 1):

1) Initiator broadcasts extended CAM (Sec. III-A).
2) Joiners evaluate whether they wish to join (Sec. III-B).
3) If so, potential Joiners transmit a `PMM` Message describing their facilities (Sec. III-C).
4) Initiator decides whether to accept the Joiner (Sec. III-D).
5) Initiator sends acknowledgment and maneuver description message (Sec. III-E).

A. Platoon Formation Advertisement Container

If the vehicle is not receiving advertisement messages from nearby platoons, it can commence the procedure to form a platoon, thus becoming an Initiator. We propose that Initiator broadcast this intention in their regular CAM messages. We propose `PlatoonLeaderContainer` as a new container to be used in `SpecialVehicleContainer`, in accordance with the standard [6, Sec.7.4] and alike the PAM message [7, Sec.6.7.3]. The container will also be used by Leaders (i.e., after platoon is formed). Table I describes the features proposed for this container, that has 63 bits.

- `targetPosition` & `LastTargetPosition`: Joiners assess if they are in the same road as the Platoon and going to the same location. We propose two fields to this end, of type `referencePosition` [8, A.124]. The `targetPosition` field defines the coordinates of the next medium/long-term waypoint on the platoon trajectory, e.g., the next exit out of a highway (even if it is kms away). These waypoints are similar to those provided by navigation systems to human drivers (e.g., Google Maps), so such systems could be providers of those coordinates. This way, the Joiner assesses if desired consumption efficiency will be attained by joining the platoon.

TABLE I: `PlatoonLeaderContainer` and field size in bits.

Field Name	Size (bits)	Description
`targetPosition`, `LastTargetPosition`	16	`RefPosition` type
`PlatoonID`	32	Randomly generated INTEGER
`WCommInUse`	3	IEEE 802.11p, 5G/NR, 4G/LTE
`PlatoonMaxSpeed`	2	Ranges: $\{v<30$, $30<v<100$, $100<v<200$, $200<v<300\}km/h$
`PlatoonType`	–	`stationType` in [8, A.78]
`AutoHumanDriven`	1	Fully autonomous, human-driven
`PlatoonSize`	3	8 size ranges ($l<10$, $10<l<50$, ...)
`VehicleHeight`	2	$h<2$, $2<h<4$, $h>4$
`AdvertiserVehicleRole`	2	AL, VL, RSU, Initiator
`EngineType`	2	Gasoline, Diesel, Electric, Hybrid

The `lastTargetPosition` keeps the last waypoint; allows the Joiner to learn if itself and the platoon are on the same road.

- `PlatoonID`: unique identifier of each Initiator.
- `WCommInUse`: announce the communication technology used for intra-platoon communications.
- `PlatoonMaxSpeed`: Joiner evaluates if maximum Platoon speed is reachable. Four classes are considered (see Table I).
- `PlatoonType`: to identify if it prioritizes small or large passengers-only or goods-only vehicles, or mixed. We propose to use the classification of `stationType` [8, A.78] (`unknown` may indicate no preference).
- `Autonomous/Human-driven`: human-drivers may prefer to join a platoon that a human leads.
- `PlatoonSize`: used if multiple Initiators exist (Sec. III-F).
- `VehicleHeight`: complements the fields in the `BasicVehicleContainerHighFrequency`.
- `AdvertiserVehicleRole`: advertiser can be an AL, VL, or Initiator (relevant for further operations).
- `EngineType`: may affect re-fueling/re-charging decisions.

Fields already present in the CAM can provide further information: `VehicleLength`, `VehicleWidth`, `lanePosition`, `vehicleRole`, and `longitudinalAcceleration`.

B. Criteria for Joiner Decision

A Joiner can process the information in the `PMM` to check if requirements are met and evaluate preferences/policy. The following requirements need to be met:

- **Same roadway:** the Joiner needs to check if it is in the same roadway as the Initiator (see Sec. III-A).
- **Platoon target speed:** the target cruise speed of the platoon should match the target cruise speed of the Joiner.
- **Communication capabilities:** the Joiner checks if it meets the communication technology requirements for intra-platoon communication.

Joiner may apply preferences/policy regarding:

- **Similarity of destination:** Joiner should check if platoon is travelling to a destination near its own (or *en-route*).
- **Autonomous/Human-driven:** assess if it is an autonomous-only platoon or mixed platoon; autonomous vehicles may be instructed to join autonomous-only platoons for liability reasons in case of an accident.
- **Engine type:** assess if platoon uses environment-friendly drivetrains (electric/hybrid).
- **Platoon Type:** assess transported loads (e.g., passengers, goods); passenger vehicles may prefer not to join goods platoons, and vice-versa.

A Joiner that receives CAMs advertising platoon formation from multiple initiators may use the above criteria to choose.

C. Platoon Management Message

If a Joiner is interested, it sends a response message namely PMM. This message is the workhorse of this and future platoon procedures. Currently, we identify seven containers; we proceed next to discuss the rationale for such fields shown in Fig. 2.

- **PlatoonMgmt-Container:** used by Joiner (Initiator) to indicate to which platoon wishes to join (confirm acceptance of Joiner).
- **NavigationInfo-Container:** same fields as in the `PlatoonLeader` container. Joiner also add its distance to the `targetPosition` in `DistanceToTarget` field.
- **VehicleInfo-Container:** describes the vehicle features, for deciding acceptance/refusal of Joiner (see next section) and for later procedures. E.g., available fuel/battery will be relevant to select VLs, and dimensions are relevant in case the Leader drives the platoon through roads with limitations.
- **CommunicationInfo-Container:** same fields as in the `PlatoonLeader` container. The `Front/back antenna` field are relevant in the case Joiner is too large and able to disrupt intra-platoon communication, platoon Initiator/Leader needs to assess if there are facilities to circumvent this.
- **SensorInfo-Container:** describes sensing capabilities of vehicle (e.g., front camera resolution) to be used for VL selection (Sec. IV).
- **Processing-Container:** is used for VL selection (Sec. IV) in order to assess the processing facilities of the members in the selection process.
- **ConnectivityMap-Container:** will be used for followers to report their measured connectivity quality to other platoon members while VL selection (Sec. IV).

D. Criteria for Platoon Acceptance

A Leader can process the information in the PMM to check if requirements are met and evaluate preferences/policy. The following requirements need to be met:

- **Joiner dimensions:** if Joiner is too large, it may disrupt intra-platoon communications.
- **Communication facilities**: the Joiner's communication facilities are checked to guarantee intra-platoon connectivity.

Leaders may apply preferences/policy regarding:

- **Joiner type:** Human passengers may feel uncomfortable joining a platoon with large trucks. The `stationType` of the `BasicContainer` of the CAM message can be used.
- **Engine type:** assess if joiner uses an environment-friendly drivetrain (electric/hybrid).
- **Autonomous/Human-driven:** a fully autonomous platoon may opt to exclude human-driven vehicles due to inefficiencies.
- **Vehicle or Platoon:** the Leader learns if the Joiner is a platoon leader(VLs/front leader) or an individual vehicle; this indicates whether it is a *join* or a *merge* operation (not discussed here).

E. Acknowledgement & Maneuver Description

To signal acceptance of a Joiner, the Initiator does so implicitly by sending a maneuver coordination message. This is necessary to instruct the Joiner about where it should join the platoon. This is less of an issue at formation time (the Joiner can just meet the Initiator at its back), but it will be relevant when the platoon grows very large and the leader needs to signal at which location in the platoon should the Joiner enter the convoy.

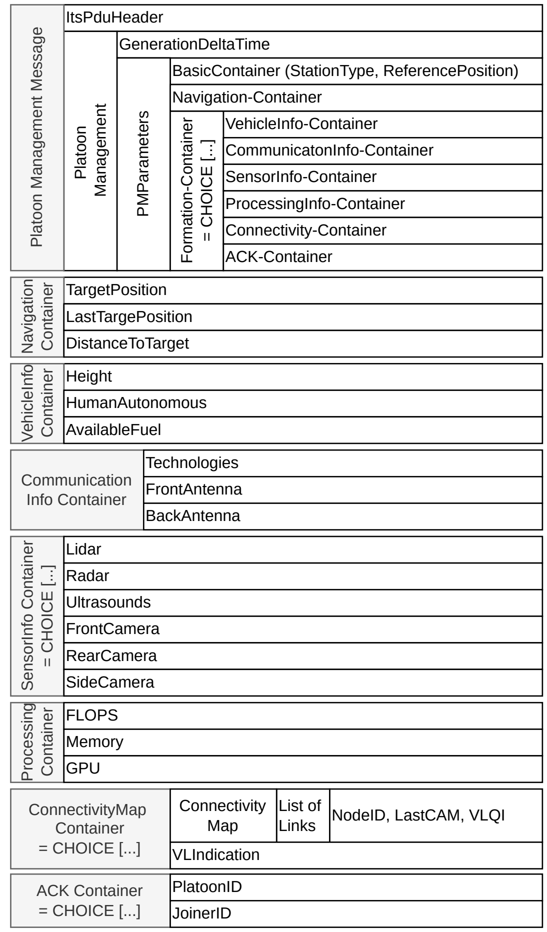

Fig. 2: Platoon Management Message (PMM).

There have been proposals of such messages, with the most relevant one being the the Maneuver Coordination Message (MCM) format [9]–[11]. We leave to future work as to whether such proposals fully match the needs of the platoon operations (*join*, *merge*), if an extension may be sufficient for that, or if a completely new message is required.

F. Procedure if Multiple Initiators Exist

If there are, in the same geographical area, multiple initiators, a procedure is required to decide whether some Initiators should become Joiners. The information contained in the `PlatoonFormationContainer` can be sufficient, at the first stage, for a distributed decision. The criteria are as follows:

1) `targetPosition` & `LastTargetPosition`: assess if any of the other Initiators is going in the same direction.
2) `Autonomous/Human-driven`: a fully autonomous Initiator may prefer not to join a human-driven Initiator.
3) `PlatoonSize`: if previous criteria are met, and if only one Initiator already has followers, this one becomes Platoon Leader and remaining Initiators become Joiners.

If more than one Initiator has followers, a tie is reached. If so, Initiators to send their PMM. Vehicle, sensor, and computation quality metrics can be used to break the tie (not discussed here).

TABLE II: Data Structure of a sample connectivity map.

VehicleID	Last CAM Time	PRR
V1	21:39:40:007	99.9%
V2	21:39:40:009	99.5%
V3	21:39:40:010	99.1%

IV. Intra-Platoon Organization

When the platoon grows to a certain extent, it becomes useful that some operations can be coordinated autonomously at segments of the platoon (e.g., *cut-in*). In addition, the front leader, henceforth called Actual Leader (AL), may not reach all members wirelessly. We explore the idea of autonomic sub-units, or **sub-platoons**, to create a hierarchical structure that facilitates platoon management and communication. These are led by VL, which the AL selects in a dedicated process. All platoon members should be associated with a sub-platoon. The AL considers the wireless connectivity but also other facilities of individual members in the VL selection process. This procedure is an enabler of the heterogeneity support of LHP, as selected VLs should have good facilities and strong connectivity to their followers.

A. Procedure

Step 1. Connectivity survey: Platoon members broadcast their CAMs regularly, and each other member can keep a record of received CAMs and compare against it the largest CAM sending interval. This enables a metric similar to Packet Reception Ratio (PRR). Members store this information in a connectivity map, a data structure that keeps, for each other member that it has received messages from, its ID, the timestamp of the last CAM message received, and the PRR (shown in Table II). The AL requests the connectivity map of followers periodically and creates a global connectivity map. If it indicates that some members of the platoon are not within reach of the leader, it starts a Virtual Leader selection algorithm.

Step 2. VL Selection: The AL computes the *Virtual Leader Quality Index* (VLQI) [2], that considers both the member's connectivity quality to followers and to the Platoon Leader (user-defined weights allow to prioritize one of the parameters). Besides VLQI, vehicle characteristics also play a role in deciding which member becomes VL. VLs should stay in the platoon for a long period, as otherwise, it may be necessary to recompute sub-platoons, leading to a message exchange overhead.

1) **Furthest Distance to Target:** candidate VL should stay in the platoon for the longest distance.
2) **Available Fuel:** candidate VL should have sufficient fuel reserves to keep up with the platoon, for the distance referred in the previous point.
3) **Processing Power:** candidate VL should have sufficient processing and storage power to manage a sub-platoon (i.e., store characteristics of members, plan maneuvers considering all members, etc.).

One of the goals of the LHP protocol is to minimize communication cost. We leave for future work to identify a closed-form solution, a heuristic or AI/ML approach to find an assignment that weighs the various criteria efficiently.

Step 3. VL Indication: The field `VLIndication` in the `PMM` is filled by the AL to indicate who is going to be VL. VLs further report that assignment to the sub-platoon members.

B. Intra-platoon Communication Network

The VL selection procedure enables the creation of a hierarchical network topology in the platoon. Considering the operations described in Section II, the following network logical topology suffices for the needs of the platoon: (i) links between VLs & AL; and (ii) links from each VL to sub-platoon members. Operations such as *join* and *leave* require both types of links. The *cut-in* operation may require solely intra-platoon communications, as a VL handles the procedure autonomously. Lastly, operations such as *merge* and *split* need to be handled solely at platoon level, thus involving solely links between VLs/AL.

V. Conclusion

We introduce **LHP protocol**, a platoon management protocol designed to handle arbitrarily long and heterogeneous platoons. On one hand, it defines an autonomic sub-structures (subplatoons) to address the extensive length; on the other hand, vehicles are asked to share their characteristics and facilities for more informed decisions. We aim that all procedures of the LHP protocol are achieved via containers and messages that are (or can become) ETSI ITS-compliant. In this paper we present two components of LHP, notably the platoon formation and sub-platoon creation.

Future work will address challenges such as finding the VL and sub-platoon assignments that best optimize the LHP protocol goals. Leveraging the intra-platoon communication network, we will describe procedures for the remaining operations (*join*, *leave*, *cut-in* and *merge*, *split*). Experimental work will be carried out to evaluate the performance of LHP protocol in successfully keeping a consistent platoon behaviour during those maneuvers. Contribution to on-going standardization efforts will be pursued.

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