Edge-Aided V2X Collision Avoidance with Platoons: Towards a Hybrid Evaluation Toolset

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***Abstract*—Infrastructure-brokered collision avoidance is an Intelligent Transportation Systems (ITS) application built on top of Vehicle-to-Everything (V2X) links. An edge-hosted ITS service receives information from road-side sensors (or CAM messages in V2X-enabled vehicles) and detects impending collisions where vehicles cannot sense or contact each other directly. If so happens, it issues a warning message through network-to-vehicle links. Another relevant ITS application is platooning, through which vehicles following each other closely can benefit of improved fuel economy, and that can be further enhanced through communication. In case of emergency braking in platoons, the response times of network and edge-hosted services must be minimal to ensure no collision amongst the platoon or any other road user. In this paper we present the implementation of a simulation framework tailored (but not limited) to evaluate the presented use-case. This complex and multi-layered use-case can be handled by a dedicated ITS service that leverages the sensing, radio and computing resources available at infrastructure and vehicles, and requires a realistic evaluation framework prior to deployment. Such framework is mostly based on simulation, albeit, to the extent possible, actual devices or services should be used; the present work is a step towards that hybrid setup.**

***Index Terms*—V2X; Platooning; Safety; ETSI ITS; Hybrid Evaluation Framework**

I. Introduction

Vehicle-to-Everything (V2X) communications [1] enables a variety of Intelligent Transportation Systems (ITS) applications, most notably expanding the situational awareness of the vehicle through *cooperative perception*. To enable V2X, vehicles are equipped with devices commonly referred to as On-Board Units (OBU), or Road-Side Units (RSU) if deployed at the road-side (in practice, OBU and RSU can be the same type of device). Such devices typically leverage IEEE 802.11p, 4G/LTE or 5G/NR technology, on top of which regional ITS stacks (namely ETSI ITS in the EU and WAVE/DSRC in the US) are deployed. Such stacks specify services mostly oriented for vehicular safety; under the ETSI ITS stack [2], the main ones are the Cooperative Awareness (CA) and Decentralized Environmental Notification (DEN).

Platooning is an ITS application referring to the operation of multiple cars following each other [3]. This holds the promise of greater fuel economy (due to less air drag) and better use of the road space. Platooning vehicles may rely solely on their sensors to follow the car in front (reactive approach), or may be aided by vehicular communications to enable active collaboration.If connected, the platoon operation can be complemented by advertisements of road traffic conditions and abnormal events to vehicles from Vehicle-to-Infrastructure (V2I) links (if using IEEE 802.11p) and Vehicle-to-Network (V2N) if using cellular technologies like 4G and 5G. V2I Road-Side Units and V2N cellular Base-Stations are both connected to the Internet and ultimately to edge and/or cloud-hosted ITS services. Communication to the exterior may often be limited to the platoon leader: in the case of V2I for avoiding data inconsistency across the platoon, and in the case of V2N due to the cost of the cellular service. In such cases, after receiving information from the network, the leader broadcasts it to the platoon using intra-platoon links.

Collision avoidance is a safety-critical vehicular application [4], [5] that can be facilitated by road-side infrastructures. In scenarios where approaching vehicles do not have line of sight to other roads (e.g., blind-corner intersections), road-side units can use information from sensors (e.g., cameras) or from the wireless messages sent by the vehicles to detect impending collisions and send wireless messages that instruct vehicles to brake on emergency. Edge computing can play a role in supporting demanding but latency-sensitive applications such as object detection in video-streams which can be used for detecting and preventing potential collisions [6].

The contributions in this work are as follows:

- Description of a selected use-case in a Vehicular Application Evaluation Framework (VAEF), that evaluates both the vehicular and wireless communication aspects of the scenario.
- Simulated evaluation of the collision avoidance use-case with two vehicular platoons interacting with a road-side infrastructure over IEEE 802.11p links.

The document is organized as follows. Section II describes the target use-case, and Section III explains the VAEF. Preliminary performance results are presented in Section IV. Section V describes next steps towards an hybrid evaluation framework. Final remarks are drawn in Section VI.

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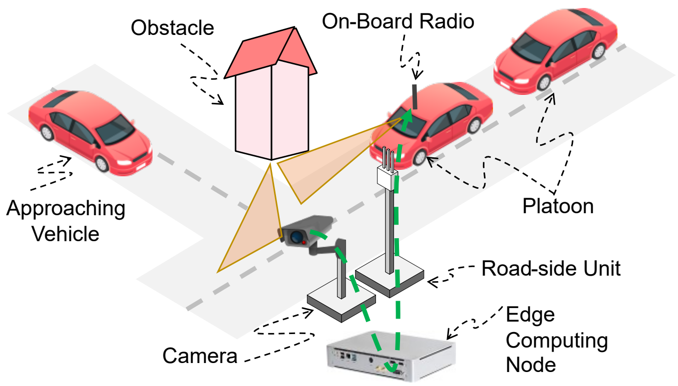

Fig. 1: Collision Avoidance use-case in which a platoon is at risk of imminent collision as it approaches an intersection & a collision avoidance system that aids in communicating and averting collision.

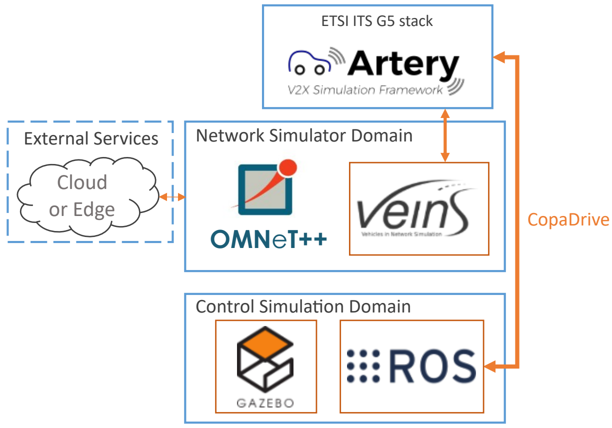

Fig. 2: Simulation architecture of the VAEF, including link to external edge nodes (right).

II. Use-case: Collision Avoidance with Platoons

In this section, we describe the composite use-case of collision avoidance in platoons, that builds from the use-cases of vehicular platooning and collision avoidance. As seen in Figure 1, our use-case is set in an intersection to which the actors, one regular vehicle and an connected platoon, are arriving and will collide if no further action is taken. Both road-users (vehicle and platoon) do not have Line-of-Sight (LoS), both visual nor wireless, due to an obstruction.

The platoon under collision imminence is equipped with an On-board Unit (OBU) that features IEEE 802.11p communication equipment. The local road-side infrastructure is equipped with IEEE 802.11p communication equipment (Road-Side Unit) and sensors (camera). The sequence of operation of our proposed collision avoidance platooning system is as follows:

1) Road-side infrastructure collects information about the location of road-users in the vicinity;
2) The possibility of an imminent collision triggers the sending of a DEN message from the RSU to the leader vehicle in the vicinity;
3) Road-users receive this information and either: (i) both actors brake; or (ii) an actor takes precedence.

The collision avoidance use-case is in accordance with the ETSI ITS [7, scenario C.1.3.2] (*Stationary vehicle warning*) and C-V2X [8, Use-case 4.10] (*Obstructed View Assist*). In line with the connected platoon, prominent European projects such as SARTRE[1] and ENSEMBLE[2] have been dedicated to the use case of safe platooning. The most relevant challenge in composing both use-cases lies in the coordinated response time of the whole platoon, which varies depending on the platoon connectivity. We assume that communication to the network is reserved to the leader, leading to a higher response time as the emergency braking command needs to be disseminated intra-platoon.

[1] http://www.sartre-project.eu/en/Sidor/default.aspx
[2] https://platooningensemble.eu/

III. Vehicular Application Evaluation Framework

In this work, we present the Vehicular Application Evaluation Framework (VAEF) over which we deployed our use-case.

The VAEF architecture consists of two simulators, a network simulator (**OmNET++**)[3] and a ROS-based[4] robotics simulator (**Gazebo**)[5]. OmNET++ models the message exchanges between vehicles, while Gazebo models the vehicle dynamics and provides a 3D visualization of the simulated world. The vehicle control is performed by **ROS** nodes, that communicate via ROS topics with both Gazebo and OmNET++ in the scope of the **COPADRIVe** framework [9].

Objective Modular Network Testbed in C++ (OmNET++): a modular component-based C++ discrete simulation framework that leverages several libraries and frameworks to execute domain-specific simulations. The frameworks required to enable vehicular networking scenarios are as follows:

- INET framework[6]: an OMNET++ model library that provides support to protocols such as TCP, UDP and IPv4. It also supports wired and wireless communication interfaces like Ethernet and IEEE 802.11. It is also the base for others simulation frameworks, i.e., SimuLTE.
- Veins framework[7] [10]: an OmNET library for handling mobility in vehicular networking simulations. It can be coupled to the road traffic simulator SUMO (not used here).
- Vanetza [11]: an implementation of the ETSI ITS suite, providing some protocols (e.g., Geonetworking) and ASN1 messages (e.g. CAM).
- Artery [12]: This provides a middleware with which external services can integrate with V2X simulations.

Robotic Operating System (ROS): an open-source framework that provides tools, libraries and conventions to support robotic applications. ROS is built on ROS *nodes*, that are processes carrying out computations. In our setup, these nodes implement the vehicle's control algorithm. Nodes can exchange information via a publisher-subscriber mechanism that ROS implements, as well as with external services.

[3] https://omnetpp.org/ [4] https://www.ros.org/ [5] https://gazebosim.org
[6] https://inet.omnetpp.org/ [7] https://veins.car2x.org/

Gazebo: a robotic simulator that provides a graphical visualization of the simulated world and models the vehicles' dynamics, sensor outputs and physical actuations. Gazebo has a high degree of interaction with ROS, is achieved via a meta-package called *gazebo_ros_pkgs*[8] that provides wrappers around Gazebo stand-alone simulation to create necessary interfaces to simulate a robot model using ROS messages and services. As such, Gazebo can exchange ROS topics regarding vehicle control and status, it can transmit real-time video captured in the simulated world (e.g., from road-side node or in-vehicle camera) as a ROS topic which can be forwarded transmitted to a external server.

CopaDrive framework: integrates the ROS-based robotic simulator Gazebo with the network simulator OmNET++. The ROS topics are exchanged between Gazebo and Artery. Vehicle kinematics and control are modelled/performed at Gazebo/ROS and forwarded in OMNET++, that sends CAM/DENM messages. At the OmNET++/Artery, each vehicle is a module composed by submodules such as `Middleware`, `Vehicle Data Provider` (VDP) and `Robot Middleware` (RM). VDP exchanges vehicle data with the Gazebo simulator via dedicated ROS topics and supplies RM with that information. RM then uses it to fill a data structure containing the fields of an ITS CAM message (e.g., speed values), that the Cooperative Awareness Service then proceeds to encode into an ITS ASN-1 compliant format. RM also provides GPS coordinates to define the position of the nodes in the INET mobility module. It is to be noted that OmNET++ operates under an event-driven paradigm and Gazebo follows a real-time paradigm. Because of this, OMNET++ waits for events generated in Gazebo to perform the communication between the vehicles.

IV. Performance Analysis

In this section we present a simulated scenario of collision avoidance with platoons moving towards an intersection and are in imminence of collision. This results serve as Proof-of-Concept (PoC) of the VAEF.

An intersection scenario was created in Gazebo, with two platoons starting at a distance of about 100 meters. The two platoons have two vehicles each, identified as Leader and follower for the first platoon and car1 and car2 for the second. In the OmNET++ representation of the same scenario, the same entities are equipped with IEEE 802.11p OBUs, and additionally an RSU exists, fitted also with a 802.11p radio. The vehicles start the simulation at 0 km/h and accelerate until reaching a target speed of 50 km/h. Followers follow the line and the leader using their internal sensors. At Gazebo simulation time instant t=50s, the RSU broadcasts a DEN message and repeats its transmission at a frequency of 33 Hz. The platoon composed of car 1 and car 2 is given precedence and crosses the intersection; the platoon of leader and follower stops as soon as possible. In the following discussion, a single run of the simulation is analyzed.

[8] http://gazebosim.org/tutorials?tut=ros_overview

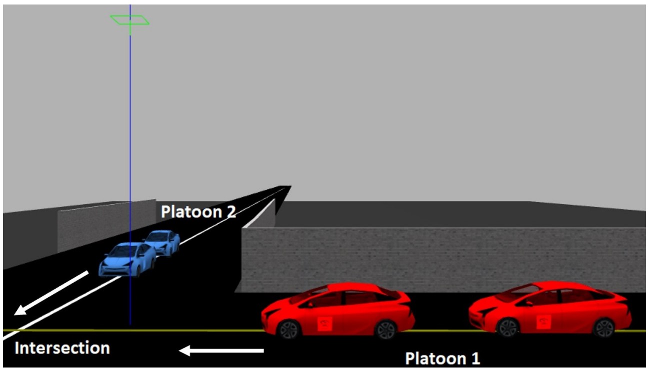

Fig. 3: Two platoons approaching intersection modeled in Gazebo. This is a simulated environment of the use-case scenario presented in Figure 1.

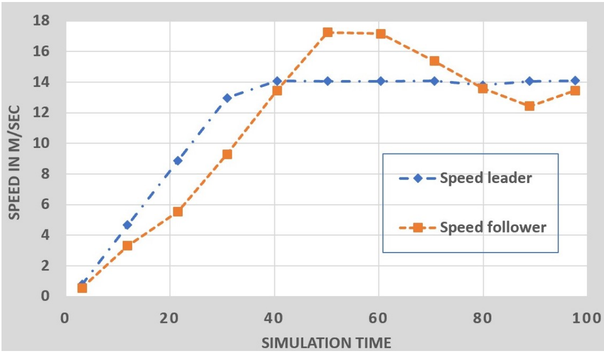

Fig. 4: Leader and the follower vehicle moving without any braking. The leader with a Target speed of 50km/h (13.8m/s) and the Follower oscillating to keep up with the target speed while maintaining the inter-vehicle distance.

Car-following & Braking Behaviour: We start by investigating the car-following behaviour in our simulation environment (i.e., if no braking occurs), shown in Figure 4. For that, we inspect the speed profile of Leader and Follower, as these do not stop throughout the experiment. After starting motion, Leader reaches the target speed of 50 km/h (aprox. 14 m/s) and keeps around that speed. Vehicle Follower accelerates at maximum rate until reaching the target inter-vehicle distance to Leader (around t=45s in simulation time), after which it halts acceleration briefly before resuming. After that, we observe an oscillatory behaviour as Follower trying to keep a target inter-vehicle distance. After Leader reaches 50 km/h, Follower, following the leader at a distance larger than the minimum, overshoots that speed until reaching again the minimum inter-vehicle distance, after which it slows down. By slowing down the vehicles move at a steady speed maintaining a constant safety distance between each other.

We now inspect the behaviour of the platoon that stops. For the sake of simplicity, the DEN message is sent at a fixed time (in this case, at t=50s into the simulation time). Figure 5 shows the speed profile of Car 1 and Car2. Akin to the previous experiment, the Car 1 accelerates steadily until

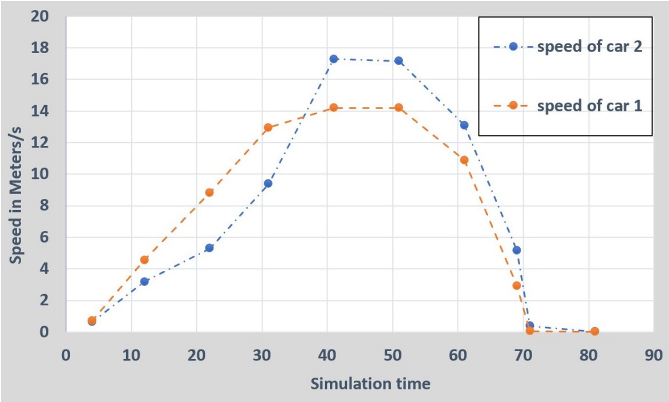

Fig. 5: Scenario with the emergency brake setup in the platoon, where car 1 and car 2 stop maintaining a safety distance following the reception of the DEN message.

reaching 50 km/h (14 m/s); the Car 2 also accelerates to keep up with the Car 1 and enters the oscillatory stage. When the emergency stop message is sent, both vehicles brake. Despite the higher speed of Car 2, that causes it to take longer to stop, no collision occurs between the members and the observed final inter-vehicle distance is 6 meters.

V. Towards a Hybrid Evaluation Toolset

Real-time identification of potential collisions based on object detection and dynamics extraction from video streams can be computationally expensive and latency-sensitive. Vehicular Edge Computing emerges as a potential solution, by allowing to offload said applications to edge nodes. The closeness of edge nodes to the end-user helps to fulfill the condition that round-trip times (RTT) between vehicle/road-side nodes stay below the application requirements.

The prototyping of the complex use-case presented in this paper using edge-hosted object detection could be properly addressed using a hybrid (simulation and emulation) evaluation framework. Vehicular dynamics and wireless communication components are handled in simulation, whereas cabled links and external services resort to real-world infrastructure. This work presented in this paper aims to be a step towards an Hybrid Evaluation Framework (HEF) for Vehicular Edge Computing (VEC), or VEC-HEF. The target architecture is shown in Figure 6; the work of [13] describes the components for connecting to the edge (or cloud).

VI. Conclusion

We have presented the implementation of an Collision Avoidance use-case involving platoons in the Vehicular Application Evaluation Framework (VAEF). We presented initial results regarding the braking performance of the platoon as it receives a ETSI ITS DEN message triggering an emergency braking action. Nevertheless, other use-cases can be explored.

In the future we aim to evolve VAEF into an Hybrid Simulation Framework for Vehicular Edge Computing (VEC-HEF) that combines simulated and real world. Vehicular dynamics and wireless communication components are handled in simulation, whereas cabled links and external services resort to real-world infrastructure. In this context, we would performing latency measurements to external nodes, and add the real-world measured delays to the simulated wireless delays obtained from the VAEF.

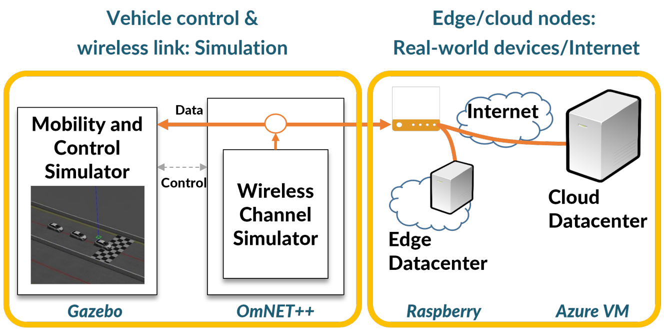

Fig. 6: Architecture of envisioned Hybrid Evaluation Framework for Vehicular Edge Computing (VEC-HEF).

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