

# Novel Communication Strategies for Platooning and their Simulative Performance Analysis

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**Abstract**—Platooning, the act of a car autonomously following its leaders to form a road train, is a hot topic in research. It has the potential to improve traffic flow on freeways, improve safety, and enhance the driving experience. A lot of effort has been put in several projects in order to implement and test systems capable of performing close car following. While the problems related to control theory seems to be solved, some questions regarding communication are still open. Wireless networking is fundamental for this application, as it is needed to manage and maintain the platoons and, clearly, has strict requirements in terms of frequency update and delay constraints. This paper surveys the literature about platooning systems and related research, identifies some open challenges, presents a simulation framework which can be used to tackle them, and outlines promising approaches.

## I. INTRODUCTION

Since the advent of Vehicular Ad Hoc Networks (VANETs) hundreds of applications have been proposed, analyzed and tested. Among these applications, platooning is often cited as one of the most visionary. It has been investigated since the eighties within the California PATH project [1] and it is still under current research.

The reasons behind such a huge investment and interest by the community are most probably the benefits that this application could provide once deployed and the challenging problems it arises.

Platooning could improve the driving experience in different ways. First of all, it has the potential to reduce, if not solve, big traffic jams on freeways and highways by improving the traffic flow [2]. The close following performed by computer-driven vehicles results in a more efficient utilization of the road, where most of the space is wasted because drivers must keep a safety distance from the vehicle in front. Such close following also reduces the fuel consumption, because the air drag is lower [3]. Lower fuel consumption clearly results in lower emissions of greenhouse gases. Secondly, platooning could improve drivers' safety, if a system fault is less likely than a human error, which is the major cause of accidents [4]. Last but not least, a vehicle which autonomously follows its leaders permits the driver to relax, read a newspaper or the emails, as shown by the recent SARTRE project [5]. Driving time would not be wasted time anymore.

From the research point of view platooning has always been extremely challenging, as it involves control theory, traffic engineering, vehicle dynamics and information technology.

The controller designed for supporting platooning, namely Cooperative Adaptive Cruise Control (CACC) [6, Chapter 7], needs indeed frequent and up-to-date information about vehicles in the platoon in order to avoid instabilities which might lead to collisions. This is where the networking community comes into play: a platooning system requires an information update frequency of at least 10 Hz [7]. Whether such communications requirements can be satisfied by the plain DSRC/WAVE stack [8] is still unclear. The aim of this paper is thus to study the current state of the art concerning communication strategies and protocols for platooning and highlight the challenges that are still open, giving some ideas on how they could be tackled.

## II. RELATED WORK

The platooning research community focused firstly on the problems connected to the automated control of vehicles. This is due to the fact that the design of a system able to maintain a constant distance between the vehicles independently from the speed is a non-trivial task. The characteristic which makes a CACC different from a standard Adaptive Cruise Control (ACC) is indeed the capability of performing a close following (in the order of roughly 5 m) independently from the speed the vehicles are currently traveling at. This is not possible with ACC, as the platoon would not be string stable, i.e., a spacing error occurring at the head of the platoon might be amplified and lead to a collision [6]<sup>1</sup>. An ACC, in order to be string stable, must keep a headway time from the vehicle in front strictly higher than 1 s, translating into a distance not smaller than 36 m at 130 km h<sup>-1</sup>. This is exactly what a human driver should do in order to respect the safety distance.

A CACC instead obtains the information about the leader and the vehicle in front by means of wireless communications: in this way a vehicle can know in advance what is happening at the head of the platoon and react quicker [6]. This kind of controllers have been investigated since the beginning by the pioneering platooning projects PATH and Auto21 CDS [1], [9], but they are still under continuous improvement either by academic research [7] or by car manufacturers, as in the case of the SARTRE project [5].

What differentiates pioneering projects from recent studies is the philosophy. In the case of PATH or Auto21 CDS, platoons were designed to run on dedicated highways, managed by a

<sup>1</sup>An example of a stable and an unstable behavior is shown in Section III.

centralized system [10]. The idea in SARTRE instead, is that platoons form autonomously, and they can travel on public motorways mixed with human driven vehicles. In both cases, network conditions are still a major concern. It is well known that 802.11-based networks can suffer of high packet loss ratios even in moderate channel load conditions. Given the frequent updates needed by the CACC in order to ensure string stability, the impact of the network performance on the safety of the overall system is non-marginal.

Due to this reason, the VANET community recently started to investigate the impact of communication characteristics on platooning performances. As an example, Lei et. al. [11] showed the impact of different packet loss rates on the performance of the CACC. Bergenhem et. al. [12] and Karlsson et. al. [13] instead focused on real world measurements, showing first the impact of the antenna positioning on the packet error rate, and then the impact of Non Line of Sight (NLOS) communications caused by obstructing vehicles. Fernandes and Nunes [14] started to investigate strategies to improve communications reliability by analyzing five different communication algorithms, all based on a slotted TDMA. Furthermore, they propose a dynamic adaptation of CACC parameters, in order to cope with different situations.

These works provide a solid foundation which made it possible to raise challenging questions that we have identified.

- Under which channel conditions a reliable communication can still be ensured?
- How many platoons can co-exist without interfering?
- How does platooning cope with other applications?
- What is the effect of background traffic?
- How can we cope with bad wireless channel conditions?

These are some of the questions that still remain open and that we intend to investigate in the near future.

### III. SIMULATION FRAMEWORK

The investigation of platooning systems under challenging conditions (i.e., high network and road traffic) can be performed by means of simulations, reducing costs and providing deeper insights. Due to this, starting from the Veins simulator [15], we have developed a platooning simulation framework [16] which enables researchers to define highway scenarios, high level applications, and communication protocols. In such a way it is possible to investigate platooning strategies, for instance understanding what is the better way of organizing the vehicles, or determine networking metrics, such as packet loss rate, delays, experienced channel load, etc.

Fernandes and Nunes [17] developed such a simulator to investigate a completely automated and dedicated highway as in the idea of the PATH project. We developed one which generalizes this idea to the SARTRE philosophy: it is indeed possible to simulate automated vehicles, together with vehicles controlled by well-known car following models, enabling the possibility of studying mixed scenarios.

We further enhanced the level of details by coupling the mobility simulator with a detailed network simulator, as we focus more on the investigation of networking related questions.

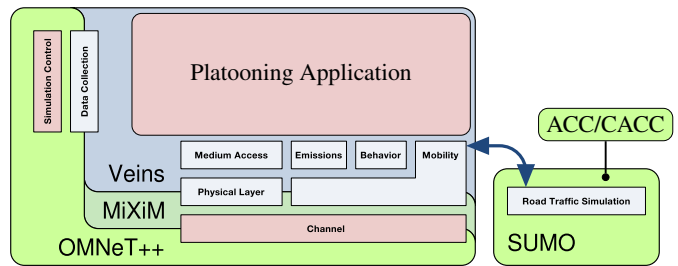


Figure 1. The Veins simulation tool extended by the platooning framework.

The Veins framework natively comes with an IEEE 802.11p and IEEE 1609.4 model [18], [19], permitting a detailed simulation of a DSRC/WAVE system.

The structure of the simulator is shown in Figure 1. Veins relies on SUMO [20] for traffic simulation and on OMNeT++/MiXiM [21] for network simulation. We extended Veins by implementing the automated controllers (ACC and CACC) described in [6] as new car following models in SUMO. The models are then made accessible from within Veins; in this way it is possible to enable/disable the controllers and change their parameters, such as the desired speed or the information received via wireless communication.

The definition of the logic of the applications and the protocols can be then easily implemented like usual OMNeT++ modules, permitting the collection of data to the purpose of successive analysis. As a simple example we compared stability properties of ACC and CACC. Figure 2 shows the headway error each car has to the vehicle in front when the leader changes its speed in a sinusoidal trend. For the sake of clarity, a positive headway error means that a car is farther from its direct leader than expected. As clearly shown in Figure 2a, the ACC is unstable, as the error is being amplified through the platoon. The CACC instead (Figure 2b) is able to react in a quicker way and the oscillatory effects are being attenuated: the last vehicles in the platoon are perfectly maintaining the desired distance.

As performed in this paper, it is also easy to make network or application layer analysis, like the one shown in [16].

### IV. RESEARCH QUESTIONS AND POSSIBLE SOLUTIONS

Once the state of the art has been surveyed and the simulation framework has been implemented, some research questions arise.

In a first step we are interested in identifying to which extent the plain IEEE 802.11p is able to support platooning. This can be done by performing some network stress tests, either by simulating a highway with several platoons or taking into account background traffic. In this way it will be possible to understand how many of the expected packets are received by platooning vehicles and with how much delay.

Secondly, it would be interesting to make an analysis of the communication requirements needed to keep the CACC safe, for example by making the leader perform an emergency

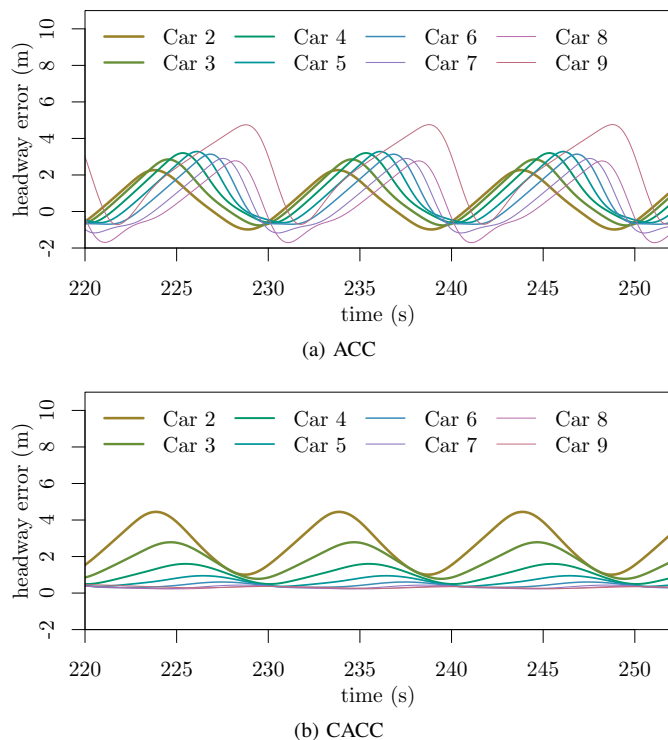


Figure 2. Comparison of spacing errors of ACC and CACC under sinusoidal variation of leader's speed, showing an unstable behavior for ACC and a stable behavior for CACC.

braking and see what happens to the platoon by changing the beaconing frequency.

Once these steps are performed, it would be possible to analyze different communication protocols and strategies, in order to determine which one is best suited for platooning. For example, comparing static beaconing using pure CSMA/CA with TDMA approaches (as in [14]), as well as transmission power control algorithms.

As a final step, even if the best of such approaches could not guarantee safety in all possible network conditions, it might be possible to determine network capabilities and react upon that, for instance by adapting the inter-vehicle distance.

## V. CONCLUSION

In this paper we have surveyed the current state of the art regarding platooning, describing the main projects, the technologies, and the research involving wireless networking. We have highlighted the potential that platooning has and how it could enhance the driving experience.

Still, some issues remain open and they must be carefully investigated and understood before the actual deployment of such system. We outlined these issues and have described the simulation framework that we have developed, which enables the analysis of vehicles' dynamics, application logic and network protocols. Such tool will be used for tackling the problems and for replying to the questions that are still lacking an answer. This enables the means of addressing the highlighted issues for which we have provided some first potential approaches.

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