Research Statement: Urban Platooning

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***Abstract*—Cooperative Adaptive Cruise Control (CACC) systems have been proven to increase road utilization, safety and decrease fuel consumption by driving with a small headway at freeway speed. Such platooning systems are usually focused on freeway scenarios and most of the current research is done for this use case. Especially in urban scenarios at traffic lights and intersections there is a lot of potential to increase the traffic efficiency and safety by applying platooning mechanisms. Most of the techniques used on freeways are not applicable for urban scenarios, as freeways are more or less a multi lane one-way road. In my PhD project I want to investigate platooning as an application for urban scenarios. For this I plan to examine platooning for signalized and non-signalized intersections in a first step, but also consider platoon formation strategies and driver models for human driven platoons. The end result should be a set of algorithms and strategies to make urban and rural traffic more efficient and safer by the use of platooning. Evaluation and analysis will mainly be done by using simulations, but not limited to that.**

I. Introduction

Intelligent Transportation Systems (ITSs) refer to a set of communication technologies to address current issues in road traffic. Recent achievements in Vehicular Ad-hoc Networks (VANETs) provide a lot more opportunities to enhance today's traffic. In recent years the research community started to work on a new concept called *platooning*. The idea of platooning is to form a convoy or a platoon of vehicles driving autonomously in close coordination under fully longitudinal and lateral control. To do so, platooning uses Cooperative Adaptive Cruise Control (CACC), which is the next evolutionary step of the Adaptive Cruise Control (ACC) of modern cars.

Segata [1] separates the platooning application in three different blocks. The first block is the controller to drive the vehicle autonomously. This includes longitudinal, so accelerating and decelerating and lateral control, so steering.

The second block is the Inter Vehicle Communication (IVC), which is essential to coordinate the platoon. Vehicles periodically broadcast their current status information like speed, acceleration, or position to all other platoon members. The exact handling of those so-called platoon beacons depends on the used CACC controller. There are mainly two different controllers used today. One is the PATH [2] and the other one the controller introduced by Ploeg et al. [3]. The main difference is that the PATH controller is not only using the information from the vehicle in front, but also the platoon leader information. This allows to establish a platoon with fixed distance in meters, which is independent from the driving speed. The data is exchanged by means of wireless communication.

The third block is assembled from application layer oriented components. One example application is logic to join or create a new platoon on a freeway.

By having a coordinated and coupled way of driving, platooning tackles multiple modern problems of traffic at once, most importantly safety and traffic congestion issues. Besides that, platooning can lead to reduction of greenhouse gas emissions and reduces stress of the driver. For instance, Alam et al. [4] show in a field operation test that fuel savings up to 7.7 % are possible while two trucks are driving in platoon at a speed of 70 km/h. Lu and Shladover [5] measure an even bigger impact of the aerodynamic drag effects. Their measurements showed fuel savings of 4–5 % for the lead truck and 10–14 % for the followers. Reducing the inter-vehicle gap does not only have an impact on the fuel savings, but also on the road utilization.

In that regard, I am currently working on the platoon's application layer. As most of the current research is focused on platooning in freeways, my plan is to focus on rural and urban scenarios. In contrast to freeways, current approaches from the platooning application layer are probably not directly applicable in those scenarios, as they need to deal with different kinds of problems.

II. State of the art

Research in the context of platooning has addressed different controllers, IVC issues, and applications. Almost all publications are focusing on platooning scenarios on freeways. However, if we see the amount of traffic bottlenecks, fatalities, and accidents in rural and urban scenarios, there is a significant need to pay more attention to those scenarios.

Intersections have a major influence on traffic. They are a bottleneck of traffic flow, increase pollution and are main reason for accidents. Lioris et al. [6] investigate the effect of using vehicular platooning on intersections. The motivation and the justifications are based on theoretical assumptions. By using theoretical calculations, the authors show that the throughput of an intersection can be increased by a factor of at least two. The idea is supported by simulations. However, the simulations are again based on theoretical assumptions and they abstract several important properties like vehicle characteristics. Lin-heng et al. [7] present a way of optimizing platoons in terms of fuel consumption while crossing traffic light controlled intersections. The idea is to obtain the upcoming traffic light phases and to choose an optimal velocity avoiding idling at red lights. The problem is transformed to a waiting time problem in front of a traffic light, which gets minimized. However, the traffic light timings are not modified, but the platoon gets split based on the pre-known timings. Simulations are performed with a platoon of 20 vehicles, but no vehicle dynamics are considered. The simulations are therefore based on assumptions without any characteristics like the acceleration or deceleration process. It should be pointed out, however, that these dynamics in particular have a high impact on the fuel consumption and traffic flow, which is completely ignored here.

III. Open questions and future work

As a part of my research I want to apply, improve, and develop techniques to use the idea of platooning in rural and urban scenarios. To the best of my knowledge, this is not done in a larger scale yet, but related work promises a big potential. Current research in urban platooning is either based on theoretical assumptions and simulations that ignore microscopic and macroscopic traffic behavior, or focusing on adjusting the platoons speed or behavior without considering Vehicle to Vehicle communication (V2V) communication.

Starting from a freeway, I want to work on rural scenarios in a first step, meaning using federal freeways and arterial roads. Both road types have different properties than freeways. In contrast to freeways, in rural and urban scenarios the amount of lanes is not well defined. They can have only one, but also multiple lanes, where the maximum number of lanes is not fixed to a certain value. The oncoming traffic might not be physically separated by using a crash barrier and roads might also cross villages, so they have very widely changing speed limits and have restrictions for overtaking. One major difference to freeways is the existence of intersections and traffic light systems. Due to the advantages of platooning, a platoon should be decomposed or even split if absolutely necessary to have the greatest positive impact in terms of road utilization, used air drag, and safety. Traditional traffic lights or even adaptive traffic lights (which take advantages of V2X communication) are probably not able to handle platoons, as they do not consider the special characteristics of such a platooning system. Also known techniques for intersection collision avoidance are probably not able to handle platoons as well. In a first step I plan to work especially on platooning in the scenario of intersections, which are either signalized or not. For signalized intersections I'll investigate different kind of existing controllers to measure their impact on platoons. For this I will make use of Vehicle to X communication (V2X) communication and not only traditional fixed timed traffic lights or induction loop-based triggers like done in related work at the moment. Using this insights I'll improve existing techniques or develop new controllers (if necessary) to handle both, platoons and human driven vehicles. Waiting times in front of intersections may also be used as an opportunity for platoon formation. This could be done in different ways, for example based on the current route or on the vehicle type. Overtaking is often difficult and different vehicle types like trucks, cars or buses introduce even more issues. An example is a bus, which blocks the road while waiting next to a bus stop on the street. Nevertheless, it might be still of a higher priority as it transports more passengers than regular cars.

On a freeway, the platoon leader is usually using an ACC to keep the desired speed and safety distance of the platoon. As an ACC is only adjusting the current speed according to the distance to the vehicle in front, it can usually not be used in urban scenarios and is at least not always usable in rural scenarios. Therefore, a platoon in rural and urban scenarios is driven by a human driver most of the time (at least for now). A car following model is needed, which especially focusses on changing traffic rules and driving conditions, e.g. intersections or traffic lights. Although there are car following models like the Krauss Model [8] or Intelligent Driver Model (IDM) [9], these models are idealistic in the sense that they abstract away from peculiarities of human driving behavior. In reality, if a new speed limit reduces the speed from 100 km/h to 80 km/h, many common car following models would model the car as going 100 km/h until the speed limit sign, then have it decelerate to 80 km/h. Reality, however, shows different possible behaviors, which in my point of view have a big influence on traffic.

References

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