Platoon Formation:
Car-to-Platoon Assignments for Individual Cars

Julian Heinovski
Heinz Nixdorf Institute and Dept. of Computer Science, Paderborn University, Germany
heinovski@ccs-labs.org

***Abstract*—Platooning (i.e., Cooperative Adaptive Cruise Control (CACC)) brings several benefits such as improved traffic flows, fuel savings and safety for the driver. Its technical feasibility and string stable operation on freeways has been shown in simulations and field tests. Many studies consider given platoons, thus, one of the next challenges is platoon formation, where individually driving cars have to be assigned to platoons. Different algorithms for platoon formation have been proposed, assigning cars to platoons at entrance ramps as well as on the freeway. Many approaches using distributed ad-hoc strategies are trying to optimize macroscopic platooning metrics such as lane capacity and traffic flows. In this PhD project, I want to research algorithms for car-to-platoon assignments which consider properties and capabilities of individual cars and produce solutions optimized regarding microscopic interests (e.g., of the drivers).**

I. Introduction

Passenger transport increased by 8 % in Europe from 2005 to 2015 [1]. The major transportation system among this transport is still the individual car (2015) [1]. This growth results in more road traffic and, therefore, more traffic jams and pollution. Hence, researchers and car manufacturers are trying to improve driving, using Inter-Vehicle Communication (IVC) via Vehicular Ad Hoc Networks (VANETs) or cellular technologies. Resulting trends are Intelligent Transportation Systems (ITSs) or cooperative driving, which utilize information from infrastructure and other vehicles. Theses developments promise a lot opportunities for improving today's traffic.

One of the biggest developments in the field of cooperative driving is Cooperative Adaptive Cruise Control (CACC) or *platooning* [2]. In platooning, multiple vehicles form a convoy, also called *road-train*, while being under full longitudinal and lateral control [3, 4]. This control is achieved by using Cooperative Adaptive Cruise Controllers, which combine data from local sensors (e.g., the distance to the previous vehicle) and information from other vehicles via IVC [2]. With periodically broadcasted beacons, all platoon members distribute information such as their current speed, acceleration and position. Commonly used controllers from the PATH project [3] or from Ploeg et al. [5], allow safe autonomous diving with constant safety gaps of 5–6 m [4, 6]. The technical feasibility of platooning and its *string-stability* was demonstrated in various fields tests [3, 6]

Platooning promises to improve today's driving in many ways. Due to those very small inter-vehicle gaps, the road utilization and, thus, the traffic flow is improved [7]. Furthermore, driving comfort and safety for the passengers are increased by the autonomous driving system [8]. And, also caused by the tight following, fuel consumption is improved due to a reduced air drag for pair-wise vehicles, especially for trucks [9]. Therefore, some truck manufacturers already implemented and test platooning systems [10].

A typical scenario for platooning is a freeway [3]. Many vehicles are driving for a long time on a straight road while keeping large inter-vehicle distances. Thus, platooning has great potential to improve driving and traffic due to all its benefits. However, in order to do utilize all of these benefits, vehicles have to get into a platoon, first of all. Studies about platooning on freeways typically just consider a given platoon for evaluating a certain platooning system or protocol. Therefore, platoon formation, i.e., forming a platoon out of multiple individually driving vehicles, is another important challenge towards platooning [11].

II. State of the art

Different approaches for solving the challenge of platoon formation (i.e., coming up with platoon assignments) have been proposed. Hoef et al. [12] calculated possible platoon assignments of trucks before the trip at a central server in an offline approach. They tried to optimize fuel consumption and trip time for a known set of transport assignments by considering simple speed changes in order to achieve fuel savings. Such optimization approaches, however, have been shown to be NP hard [13]. Moreover, these offline approaches need to know the set of trips a priori as it is used as an input for the optimization algorithm.

In comparison, online, or rather ad-hoc, approaches do not need the set of trips a priori as they only consider currently available vehicles. Several studies used a distributed (ad-hoc approach), where vehicles are sorted into platoons at the entrance ramp of the freeway [14]. These approaches typically group cars according to their destination and let them enter the highway as an already constructed platoon. As most often the platoon length is optimized, these approaches introduce additional waiting times for the vehicles at the entrance ramp, thus, increasing the overall trip duration.

Considering a private passenger transport, a driver probably does not want to wait at the entrance ramp until a platoon is constructed. To avoid that waiting time, vehicles can enter the freeway immediately and search for possible platooning opportunities during the trip. Khan and Bölöni [15] developed a system for ad-hoc convoy formation on freeways, which evaluates the cost and benefit of forming a platoon with other vehicles in proximity. Later, pairwise coordination of Heavy Duty Vehicles (HDVs) for distributed ad-hoc formation has been done in order to achieve fuel savings [16].

The aforementioned protocols allow only basic ad-hoc formation as they just consider other vehicles in close vicinity. IVC allows more advanced decision logic by utilizing information from other vehicles [17]. After entering the freeway, vehicles search for platoons and join feasible ones, if there is any in vicinity. Otherwise, a new platoon has to be formed among other vehicles.

Approaches using ad-hoc formation so far have been assigning cars to platoons in order to improve macroscopic metrics such as lane capacity and traffic flow. However, when considering a more microscopic level, i.e., metrics that directly influence and are of interest to a driver, this might not be optimal as individual properties and capabilities of the trips and cars, i.e., destination, desired driving speed, trip duration, fuel consumption, are not considered. Caballeros Morales et al. [18] proposed a distributed clustering algorithm to group cars according to their destination, speed, and position. It forms groups of vehicles by minimizing their respective deviation, in order to increase lifetime of clusters among the mobility pattern of vehicles.

Following a similar approach, we recently studied platoon formation from the perspective of individual cars by optimizing platoon assignments regarding individual capabilities and properties [11]. Simulations using simple heuristics already indicate that these, and the willingness to compromise, have a huge impact on the resulting assignments.

III. Open questions and future work

In this PhD project, I further want to research platoon formation for individual cars, in order to come up with better car-to-platoon assignments for the individual drivers on a microscopic level. I want to continue exploring different strategies and algorithms as well as different optimization problems and goals, extending our recent work [11]. A driver would typically only care about his individual improvement from platooning, therefore, this should be optimized at first. Of course, the impact on macroscopic metrics such as the road utilization and traffic flow should be evaluated as well.

Besides considering individual properties of cars, such as vehicle capabilities and trip properties, I want to incorporate maneuvers, such as merging and splitting platoons, as possible options. Furthermore, the difference between distributed and centralized formation, or even a combination of both, is of interest. Moreover, the impact of different wireless communication protocols and technologies on the formation results can be investigated.

Evaluation and analysis of different approaches, algorithms, and optimization goals will mostly be done, but are not limited to, means of simulation, using the openly available platooning simulation framework Plexe [19]. It allows to simulate realistic driving and networking behavior using Sumo and Veins, respectively. However, in order to use Plexe for studying platoon formation in depth, some implementation work has to be done to achieve a stable application base and a set of sophisticated implementations of platooning maneuvers.

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