Poster: Scalable Simulation of Platoon Formation Maneuvers with PlaFoSim

Julian Heinovski*, Dominik S. Buse*†, and Falko Dressler*
* School of Electrical Engineering and Computer Science, TU Berlin, Germany
† Software Innovation Lab and the Department of Computer Science, Paderborn University
{heinovski,buse,dressler}@ccs-labs.org

***Abstract*—Platooning is one of the most challenging applications of Intelligent Transportation Systems (ITS). While the microscopic control of vehicles in a platoon can already be simulated quite accurately, the scalable simulation of maneuvers and platoon formation is still challenging. To bridge this gap, we propose PlaFoSim, a tool for simulation of platoon formation in large-scale freeway scenarios. PlaFoSim aims to facilitate and accelerate the research of platoon maneuvers and formation – new algorithms can easily be integrated using Python modules. We illustrate the capabilities of PlaFoSim and also showcase its scalability in a large-scale simulation setup.**

I. Introduction

Platooning on freeways is a promising application of Intelligent Transportation Systems (ITS) [1]–[3]. Using Cooperative Adaptive Cruise Control (CACC), it allows driving in convoys with extremely small safety gaps (e.g., 5 m), while still providing string-stability and safe operation. Platooning thus promises to improve traffic flow, passenger safety, energy consumption, and passengers' comfort. While the microscopic simulation of platoons has seen significant research already (e.g., Plexe [2]), the large-scale simulation of the formation of platoons still leaves a lot of open questions [1]. Large scenarios with many vehicles are required to observe effects on resulting platoons and their impact on metrics like travel time, fuel consumption, or traffic flow. The distribution of traffic may have significant influence on the outcome of platoon formation, e.g., due to chain reactions and other statistical artifacts. Thus, these large scenarios also need to be repeated many times and observed over a long period of time.

Existing (microscopic) platooning simulators focus on detailed simulation of mobility, control, or maneuvers [2], [3]. This high level of detail (and their coupling with other tools) leads to high computational complexity, making large-scale simulation studies very slow. A typical example is the popular road traffic simulator SUMO [4], which also lacks detailed platooning support. For studying ITS applications such as platoon formation, many of these microscopic details can easily be omitted. Analyzing platoon formation algorithms with existing simulators is thus rather difficult as either the required scale is not supported or the simulation time becomes prohibitively long.

In this paper, we therefore present *PlaFoSim*,[1] a simulator for platoon formation. PlaFoSim serves as an integrated, stand-alone tool for fast and easy simulation of platoon formation algorithms in large-scale freeway scenarios. Vehicles are still simulated individually (microscopic) such that their maneuvers, behavior, and platooning benefits can be observed. This is required for studying the impact of platooning on the individual vehicles/drivers [1]. But the level of simulated detail is tailored to the needs of platoon formation assessment, thus greatly reducing computational complexity. New platoon formation algorithms can be easily implemented as Python modules and compared to existing ones. Scenario configuration is done via high-level parameters such as road length, desired vehicle count, and platooning penetration rate. PlaFoSim thus facilitates and accelerates the research of platoon formation algorithms.

[1]https://www.plafosim.de/

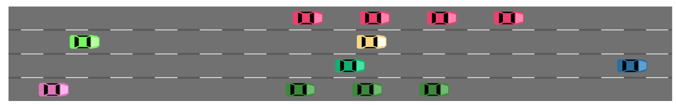

Figure 1. Screenshot from the Sumo-based live GUI of PlaFoSim: a freeway with 4 lanes, many individual vehicles, and 2 platoons.

II. PlaFoSim: The Platoon Formation Simulator

PlaFoSim is a simulator for platoon formation on freeways. It is implemented as an integrated, stand-alone command-line tool based on Python 3 and only a few additional libraries. The focus of the simulation is on vehicle-to-platoon assignment algorithms. Thus, platooning mobility, wireless communication, and platooning maneuvers are implemented in a more abstract way. PlaFoSim enables fast integration of new algorithms, easy configuration via command line arguments, and fast simulation of large-scale scenarios. For easy inspection, debugging, and show-casing, PlaFoSim uses Sumo to integrate a live GUI (see Figure 1). PlaFoSim can record statistics such as vehicle speeds and positions, fuel consumption, and emissions,[2] as well as platoon formation data, platoon sizes, and performed maneuvers. Produced traces can later be visualized in the GUI.

A. Architecture

PlaFoSim is based on the concept for microscopic simulation of multi-lane traffic proposed by Krauß [5]. Thus, its main simulation loop consist of the following steps: (1) insert new vehicles, (2) trigger actions (e.g., running formation algorithms, recording statistics), (3) execute lane changes, (4) execute car-following models to update vehicle speeds, (5) update vehicle

[2]using HBEFA model PC_G_EU4 of version 3.1

positions, and (6) perform collision checks among all vehicles. Afterwards, PlaFoSim updates the live GUI, records further statistics, and advances the simulation time.

B. Scenario & Simulation Configuration

PlaFoSim focuses on simulating long freeways with multiple lanes and periodic on-/off-ramps, which are used by the vehicles to enter and leave the freeway. Besides, simulation time and steps can be configured. Vehicle influx is configured in a macroscopic way via (1) a flow with constant insertion (e.g., by departure rate) or (2) a constant number of vehicles. Independent of the method, vehicles drive trips of configurable length between on-/off-ramps. The desired driving speed of a vehicle can be sampled from a normal distribution. A penetration rate chooses between human driving and platooning. To reduce effects from the initial transient period, PlaFoSim allows pre-filling the scenario according to a target density (i.e., vehicles per km and lane) before the simulation starts. Deterministic variation of stochastic behavior can be achieved through a random seed.

C. Vehicle Dynamics

Longitudinal (speed) and lateral (lane) control of vehicles follow the models also used in Sumo and Plexe. This facilitates the validation of the results. It also enables a migration path for porting promising platoon formation strategies from PlaFoSim to these simulators with higher levels of detail. Multiple car following models are implemented for longitudinal control: A Krauss model [5] for human-driven vehicles, Adaptive Cruise Control (ACC) similar to Plexe (cf. [6, Eq. 6.18]), and CACC for platooning. CACC abstracts communication and platoon control by transferring the speed of the leader vehicle to all its followers without delay. Lateral control for lane changing is also modeled following the Sumo implementation. Vehicles aim to stay on the rightmost lane, but can perform multi-lane overtake maneuvers if needed. Platoons can also perform overtake maneuvers by executing lane-changes simultaneously.

D. Platoon Formation

Platoon formation is performed within *actions*, either by individual vehicles or centrally coordinated. Actions in general are triggered at every simulation step but the period for executing the platoon formation algorithms can be bigger (e.g., 60 s). Forming platoons typically consist of three steps: (1) data collection of available vehicles and platoons, (2) computation of vehicle-to-platoon assignments, (3) execution of maneuvers.

Vehicles know other vehicles within a certain range whereas central coordinators have complete knowledge about the scenario. Desired assignments are fulfilled by join maneuvers which teleport vehicles to their designated platoon position, considering the approximate time for approaching.

III. Case Study

We showcase the scalability of platoon formation simulation in a larger scale freeway scenario, i.e., a 3-lane freeway of 500 km with on-/off-ramps every 10 km. Vehicles drive random trips of 50 km between two ramps, at a desired speed sampled from 90–170 km/h. New vehicles spawn at random ramps to roughly maintain the initial total of 1500 vehicles (i.e., one vehicle per km and lane). The simulation runs for 3600 s (1 h) to demonstrate the scalability of PlaFoSim.

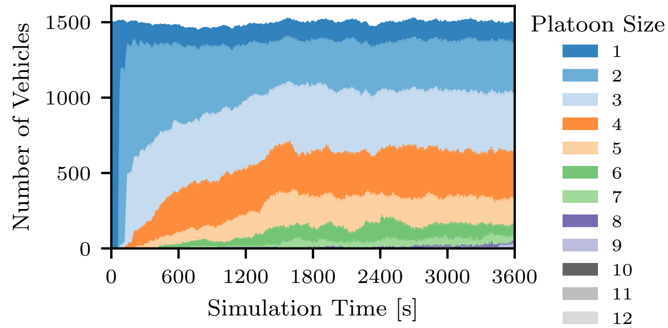

Figure 2. The number of vehicles in platoons of different size during the entire simulation in a cumulative, stacked representation.

Vehicles initially use ACC but start forming platoons after 60 s using the *distributed* approach presented in [1]. Once a platoon leader is found, followers initiate a join maneuver. Followers then stay with the platoon until their destination, at which a leave maneuver is performed.

Figure 2 shows the resulting platoon sizes in one exemplary simulation run. Vehicles initially drive individually (as platoons of size 1). Over time, some platoons collect more followers as new platoon assignments are computed every 60 s after vehicle departure. After about 1800 s, the composition of platoons remains quite stable. At this point, most platoons have a size of 2–4 vehicles, though some temporarily reach up to 12 members. Only around 10 % of vehicles are not part of a platoon.

IV. Conclusion

We propose PlaFoSim, a new simulation toolkit for studying platoon formation in large-scale freeway scenarios. We described the necessity of such a simulator for platoon formation algorithms, illustrated its structure, and showed its capabilities in a case study. The Python-based tool allows the integration of new formation algorithms and simulation configuration through high-level parameters. In future work, we aim to further improve the performance of the simulation, integrate more platooning maneuvers (e.g., merge or split), and support multiple vehicle types within the same simulation.

References

[1] J. Heinovski and F. Dressler, "Platoon Formation: Optimized Car to Platoon Assignment Strategies and Protocols," in *IEEE VNC 2018*, Taipei, Taiwan: IEEE, Dec. 2018.

[2] M. Segata, S. Joerer, B. Bloessl, C. Sommer, F. Dressler, and R. Lo Cigno, "PLEXE: A Platooning Extension for Veins," in *IEEE VNC 2014*, Paderborn, Germany: IEEE, Dec. 2014, pp. 53–60.

[3] J. Mena-Oreja and J. Gozalvez, "PERMIT – A SUMO Simulator for Platooning Maneuvers in Mixed Traffic Scenarios," in *IEEE ITSC 2018*, Maui, HI: IEEE, Nov. 2018, pp. 3445–3450.

[4] P. Alvarez Lopez, M. Behrisch, L. Bieker-Walz, J. Erdmann, Y.-P. Flötteröd, R. Hilbrich, L. Lücken, J. Rummel, P. Wagner, and E. Wießner, "Microscopic Traffic Simulation using SUMO," in *IEEE ITSC 2018*, Maui, HI: IEEE, Nov. 2018, pp. 2575–2582.

[5] S. Krauß, "Microscopic Modeling of Traffic Flow: Investigation of Collision Free Vehicle Dynamics," PhD Thesis, Mathematical Institute, Köln, Germany, Apr. 1998.

[6] R. Rajamani, *Vehicle Dynamics and Control*, 2nd ed. Springer, 2012.