5G-Enabled Automated Truck Platoons in Urban Areas

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Research Article

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Abstract

Transport and logistic sector is expected to obtain large benefits thanks to the implementation of 5G. This work proposes a framework based on 5G technology for Automated Truck Platoons (ATP) in urban areas to reduce energy consumption and Greenhouse Gas (GHG) emissions. More specifically, 5G features such as low latency communication (uRLLC), massive Machine Type Communication (mMTC) and enhanced mobile broadband (eMBB) are deployed with the Green Light Optimal Speed Advisory (GLOSA) to achieve the optimal speed of Automated Truck Platoons. The results of a preliminary test implemented in the Port of Hamburg show that 5G GLOSA ATP is promising in terms of energy consumption and GHG emissions reduction and increased truck platoon stability.

Keywords: 5G, Green Light Optimal Speed Advisory, truck platooning, Connected and Autonomous Mobility (CAM)

1 Overview and Motivation

A number of emerging advanced Connected and Autonomous Mobility (CAM) services, such as dense truck platooning implemented in port areas, relies on and are expected to exploit the real potential of advanced 5G capabilities. When considering the 1,500 billion tons-km of freight traffic via road in EU-28 (Eurostat 2018), advanced CAM services appear to offer a business case to the industrial sector suitable to trigger the expected deflagration of 5G in Europe. 5G promises to address diverse and rather demanding performance requirements of a wide range of applications, in terms of data rates, capacity, security, reliability, availability, latency and impact on battery life. Although the 5G frequency bands have been assigned to European Member States, and standardization activities have yielded advanced features (with 3GPP Release 16/17), the number of 5G trials have not exploded, raising some concerns about the actual ability in monetizing the 5G-enabled applications. A possible problem could be the gap that exists between the knowledge of telecommunications experts and of applications' developers [Trichias et al, 2021].

The objective of this work is to propose a framework based on 5G technology for Automated Truck Platoons (ATP) to measure and reduce energy consumption and Greenhouse Gas (GHG) emissions in urban areas. More specifically, the innovative approach consists of traffic management actions linked to traffic light signalling used in 5G enhanced Green Light Optimal Speed Advisory (GLOSA). The framework is tested on a mini-platoon that travels along the transport network that connects Hamburg city center to the maritime port and on test field for autonomous driving. The mini-platoon is formed by a lead platoon vehicle and following vehicles. To keep the platoon safe and the distance stable, the speed range of the lead vehicle is transferred to the platoon followers. For this purpose, vehicle-to-vehicle communication (V2V) with low latency run times (<50 ms) is implemented to guarantee the operation of the truck platoon in urban traffic conditions where platooning is challenging. Furthermore, the traffic signal forecast is sent to the vehicles and the drivers to adapt their speed to optimum according to road and traffic conditions.

With the increased use of applications, the communication between vehicles in urban areas is expected to further degrades [Alfred et al, 2016]. For this reason, the proposed framework makes use of ultra-reliable low latency communication (uRLLC) and Enhanced mobile broadband (eMBB). To navigate a platoon stable and safe within the busy urban road network, avoiding collision with Vulnerable Road Users (VRUs) such as pedestrians and bicycles, the GLOSA (Green Light Optimal Speed Advisory) application is deployed. Additionally, 5G enabled Precise Positioning is used to enhance the accuracy of GLOSA and to improve the collision warning alert message. The proposed framework is expected to allow significant fuel savings, to reduce emissions due to frequent stop and go of the vehicles and to give stimulus to logistics service providers to adopt similar solutions.

The paper is structured as follows. Section 2 presents the main works related to truck platooning and to GLOSA. Section 3 describes the main features of 5G GLOSA for Automated Truck Platoons which is the framework that is tested in the city of Hamburg. The results of the test performed using mini-platoons of vehicles in two different locations of the Hamburg urban area are presented in Section 4. Finally, Section 5 reports the conclusion.

2 Related works

In this section, a selection of the literature regarding truck platooning and GLOSA is presented. Most of the studies have been focused on the results of demonstrations performed with truck platoons on the highways. In Tsugawa [2014], for example, the result of a test involving a platoon formed by three heavy trucks performed in the context of the Energy ITS project is presented. The author found that the platoon traveling with a distance of 4.7 meters between vehicles allowed to save 14% of fuel consumption. As pointed out by Hegde et al [2019], the success of platooning depends on the distance between vehicles and on the possibility to avoid accidents. However, the possibility to keep the safety distance depends on the V2V (Vehicle-to-Vehicle, V2I (Vehicle-to-Infrastructure), V2X (Vehicle-to-everything) communication, Quality of service (QoS) and on the precise position of the vehicle [Raiyn, 2020]. A test on 5G for truck platoon that took place on an expressway has been presented by Serizawa et al [2019]. The trial was able to assess the capability of 5G New Radio (NR) V2X communication to reduce latency of 50 ms compared to 4G LTE. There are therefore very few examples of works that tackle the problem of implementing truck platoons in urban areas. One of such examples is presented by Liang et al [2016] who describe the results of an experiment to evaluate the possibility of a platoon to merge in different traffic conditions. They found that light traffic conditions are able to delay platoon merging.

Green Light Optimized Speed Advisory (GLOSA) is an application based on V2I communication. Vehicles recieves information on the optimal speed to catch the green light at an intersection [Stebbins et al, 2017]. This solution can have positive impacts with regard to the economic and environmental aspects. In Coppola et al [2022], microsimulation has shown that GLOSA allows to save consumption of 5% of both electric and not electric vehicles. According to Treiber et al [2000], minimizing acceleration and brakings can save about 30% of fuel consumption and combustion engine related emissions. As found in several measurements by traffic researchers, NOx emissions show a rather extreme decrease whenever Start-Stop engine ignition is applied [Favez et al, 2009] and [Fonseca et al, 2011] and reliable GLOSA information would help to further reduce these emissions. This is shown, for example, by the *arrive* project[1] in which fuel consumption and pollutant emissions were examined in

[1] *arrive* is a research project of the city of Munich covering the entire traffic management spectrum. One of the objective was to ensure the quality of the traffic management and the improvement of Green Light Optimized Speed Advisory (GLOSA).

detail in a car along an inner-city test route, which is characterized by several traffic lights. The green wave and the extension of the green time resulted in savings of almost 50% compared to normal conditions without GLOSA. On the other hand, Klöppel-Gersdorf and Grimm [2020] analyse GLOSA algorithms with reference to the behaviour of diesel vehicles and found that these vehicles (e.g., heavy trucks or busses) were negatively impacted by platoons with GLOSA because they had to break and accelerate when following them. In this regard, it must be considered that a combustion of one liter of fuel corresponds to approximately 2.4 kg of CO2 when using petrol or 2.6 kg of CO2 when using diesel, depending on the quality of the fuel used. In another study, Chandramouli et al [2019] found that truck platoons allow lead truck to save 4% of fuel and 10% the following truck.

In Katsaros et al [2011], a simulation scenario has allowed to test the activation time. The authors found that 350 meters was an optimal distance to allow for a prompt reaction time from the driver. The authors also found that vehicles not equipped with GLOSA also benefited from it in terms of traffic and fuel efficiency. GLOSA can be single-segment or multi-segment. The difference between the two is that, in the former, vehicles receive information on the optimal speed with reference to the nearest traffic signal; while in the latter, vehicles receive information on the optimal speed for a set of segments head the vehicle. Seredynski et al [2013] found that multi-segment approach outperforms in terms of fuel consumption and travel time.

A strategy for platoons to increase the throughput at intersection has been proposed by Feng et al [2019]. Their approach consists of minimizing the arrival time at intersection of a vehicle during green light and to deploy a trajectory planning method based on GLOSA to optimize the acceleration of platoon leaders and followers. GLOSA has been proposed for autonomous vehicles. In Nguyen et al [2016], the authors propose an approach, R-GLOSA, to optimize speed of vehicles to arrive at intersection when the light is green. The method consists of collecting information from the Road Side Units (RSUs) on all cars along the road segment. The car density is measured and, based on this information, the target speed is calculated. The authors found that R-GLOSA outperforms GLOSA in terms of travel time and waiting time. Finally, Stebbins et al [2017] presented a work to determine the platoon leader in natural traffic conditions and to suggest delays instead of optimal speeds. According to the authors, suggesting delays to following vehicles makes GLOSA more effective in terms of reduction of fuel consumption and GHG emissions.

3 5G GLOSA for Automated Truck Platoons

Trucks have the highest fuel consumption of road infrastructure using vehicles. GLOSA can, therefore, help to reduce emissions by allowing Automated Truck Platoons along pre-defined logistics corridors.

Whereas traditional GLOSA technology focuses on implementing single-vehicle speed advise, 5G GLOSA for Automated Truck Platoons goes far

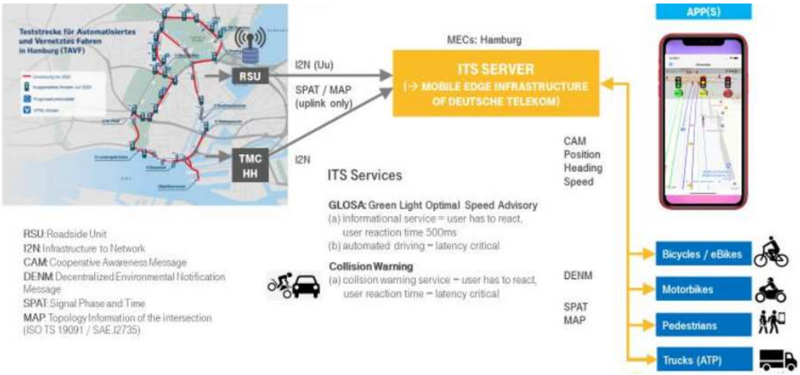


Figure 1 GLOSA APP technology as planned in the TAVF test Field

beyond this concept as it enables green light optimized speed advisory for a platoon of trucks. The objective is to minimizing pollutant emissions by taking into account real-time data of the vehicles driving within the platoon as well as green light and green wave optimized traffic signalling [Stebbins et al, 2017]. For this purpose, precise positioning information and an exchange of telemetric sensor data between the truck and the 5G modem inside the traffic controller is provided using the adequate 5G functionalities, including the MEC server of the 5G network as well as the ultra-reliable low latency communications (uRLLC), massive Machine Type Communications (mMTC) and enhanced mobile broadband (eMBB) features. The innovation of the proposed framework lies on the up link of traffic light signal phase and time information that are combined with the specific topology information of the intersection leading to a Signal Phase And Timing (SPAT) and MAP message which is transmitted to the 5G-Mobile Edge Computing (MEC) Server and from there to the GLOSA application, as shown in Figure 1. Only by applying these functionalities, the Automated Truck Platoons can achieve driving with optimum speed within the logistics corridor or to wait on allocated parking places and the Pre-Port Parking facilities waiting for their time slot of goods delivery to the shipping terminal.

The Truck Platoon is equipped with Telematic On-Board Units and, while traveling, is exchanging sensor data and video control data with the Mobile Base Station. Video data exchange is optional for the purpose of control messages to keep the platooning at distances required for stability and safety.

Complementary to this, Figure 2 presents decision gates to operate trucks platooning safe and driving at constant distances. Control messages refer to the different roles of the lead platoon with a driver on board and the follow platoons which will be operated in the long-term driverless Level 5. The GLOSA APP analyses the lead vehicle and its driver behaviour to adapt the GLOSA speed advice for the follow vehicles of the platoon. Figure 2 shows how the GLOSA enabled Truck Platooning could be operated by applying state of the art traffic light priority technology. First, it is needed to keep a minimum distance between lead and follow platoon vehicles. The minimum distance should

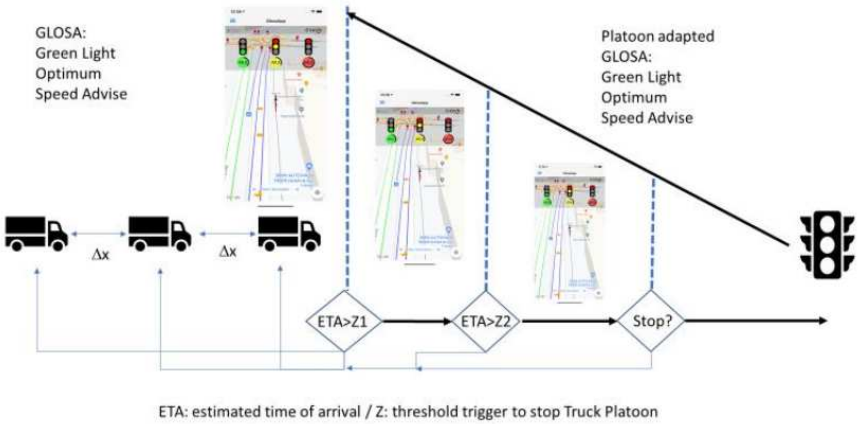


Figure 2 5G GLOSA ATP – Decision Gates

lie in the range of 3 to 5 meters, balancing safety and stability of the platoon's operation.

3.1 5G Network Architecture

The 5G mobile network is a big step to provide many new features for telecommunication customers. From a core network evolution perspective, there are two main steps to supporting 5G New Radio (NR). The first step – a 5G Evolved Packet Core (EPC) with 5G NR Non-Standalone (NSA) operation, is to move forward from the existing EPC. There are three major advantages of 5G:

- Massive machine to machine communications (mMTC) – also called the Internet of Things (IoT) that involves connecting billions of devices without human intervention at a scale not seen before.
- Ultra-reliable low latency communications (uRLLC) – mission-critical including real-time control of devices, industrial robotics, vehicle to vehicle communications and safety systems, autonomous driving, and safer transport networks.
- Enhanced mobile broadband (eMBB) – providing significantly faster data speeds and greater bandwidth. New applications will include fixed wireless internet access for homes, outdoor broadcast applications without the need for broadcast vans, and greater connectivity on the move.

In the 5G NSA approach, the existing 4G core (EPC) is working as an anchor network mainly for signaling purposes. This EPC is combined with new extended radio functions – focused on the provisioning of additional mobile bandwidth capabilities (5G New Radio – 5GNR).

The second step – 5G NR Standalone (SA), is a new 5G Core (5GC) using a service-based architecture (SBA). The new architecture is fully software-based and will support network slicing. Network slicing will offer separated virtual networks for dedicated clients. With this approach, the mobile operator can offer qualities (e.g. signal latency) and capacities (e.g. bandwidth) to the network. This service provides extremely high service-level agreement (SLA) levels.

3.2 MEC and uRLLC

The 5G GLOSA for Automated Truck Platoon framework establishes a V2X information system by combining 5G functionalities with GLOSA to enable automated truck platooning. The optimised trajectory planning for automated vehicle manoeuvring across intersections enabled by real-time information on current and predicted traffic light signalling requires reliable connectivity and analytic capability with a low latency below 10ms. By using a MEC between the 5G core network and the connected vehicles network transfer delays are reduced to meet the specific ultra-reliable and low-latency requirements necessary to serve automated truck platoons.

The MEC allows to provide information to the connected vehicles by processing and combining mission-critical traffic information with manoeuvres of the vehicles and infrastructure data from the cloud. Efficient and safe driving inside a platoon requires information being shared among the platoon as synchronous as possible. The following vehicles should be on-time aware of relevant actions of the leading vehicle (imminent reduction/increase of speed), otherwise unnecessary braking or the dissolving of the platoon cannot be prevented.

3.3 Precise Positioning

The uRLLC functionality is a prerequisite for the required precise positioning. While precise positioning of stationary objects does not require the use of 5G technologies, the application on fast-moving vehicles as passenger cars, light, and heavy commercial vehicles requires the improved connectivity capabilities of 5G as uRLLC. Under consideration of the movement of the platoon, the impact of uRLLC will further be improved by 3GPP Release 16, which introduces enhancements of session continuity and therefore improves the reliability of low latency services.

The 5G GLOSA for Automated Truck Platoon (5G-GLOSA ATP) needs the precise positioning on lane-level. First, this requires an accuracy of the position within an error bound of lateral of 0.57m (0.10m for 95%) and longitudinal of 1.40m (0.48m for 95%) on freeways [Reid et al, 2019]. Therefore, conventional GNSS position information will not be sufficient. Secondly, the given position has to be provided in a high frequency and a low latency to be reliable in a fast-moving vehicle. The 5G-GLOSA ATP combines uRLLC with the precise positioning service cloud-based GNSS corrections service that provides accuracy for the position of up to 0.10m. It should be noted that network centric Precise Positioning services do not necessarily require 5G and are already available in 4G/LTE. Nevertheless, when it comes to rolling out any type of scalable service uptake, e.g. reliable Floating Truck Emission Data or Collision Warning for Automated Truck Platoons in a European metropolitan Region such as Hamburg, the core functions of the 5G network uRLLC, MEC and network slicing become crucial elements of the services.

3.4 Local Traffic Management System

For the first stream (see Figure 3), a definition of an appropriate truck route is needed beforehand. The stream itself consists of online traffic light and detection data as well as configuration information for the individual intersections along the route. Detection data are needed to forecast at intersections with a traffic dependent, i.e. reacting on the current traffic situation, control logic. In addition, the configuration of the traffic control logic for each intersection is mandatory, since it describes the schedule of the traffic logic during the day and maps the detection data to their relevant detectors and traffic signs. Based on this data the Traffic Light Forecast (TLF) module calculates continuously the forecast and itself generates a stream of present and forecasted traffic light states (IM1).

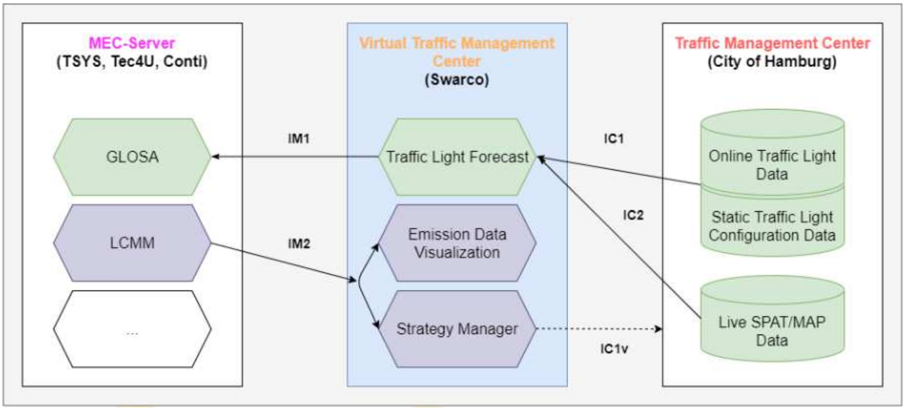


Figure 3 Virtual Traffic Light Management System

The second stream (IC2) consists of data generated at intersections alongside. Data are delivered in an XML-encoded version of the ETSI C-ITS messages MAP (intersection topology) and SPAT (signal phase and timing). The SPAT data already includes prediction data based on a local forecast performed inside the individual traffic light controller. The TLF module will convert these data and streams them through interface IM1. Obviously, to produce a meaningful GLOSA application, it is required that the traffic light data has very low latency and the forecast is performed with lowest delay possible.

Truck and Emission Data (FTED) are provided by the LCMM module on the MEC-server via interface IM2 for the route. They are consumed by the visualization module, which shows the emission data with and without the influence of GLOSA on truck driving. In addition, IM2 data are used to evaluate the current emission situation. In case of high emissions, a strategy to decrease emission values can be suggested. This could be an alternative routing for trucks or an adapted traffic control scheme.

4 Results and Discussion

This section presents the results of the preliminary test performed with a mini-platoon formed by two vehicles and another mini-platoon formed by seven vehicles. Both test have been carried out in the city of Hamburg, in the context of the 5G-LOGINNOV project which aims to demonstrate an improvement in logistics processes by using 5G technologies in the port areas. The EU-funded Horizon 2020 project demonstrations take place in the three port cities of Athens (Greece), Koper (Slovenia) and Hamburg (Germany). In Hamburg, the main focus is the reduction of fuel consumption and GHG emissions thanks to 5G-GLOSA for Automated Truck Platoons (ATP). The impact of the 5G GLOSA for ATP is assessed in terms of energy consumption and GHG emissions. The second test is focused on the behaviour of the mini-platoon during high traffic conditions.

4.1 Hamburg Living Lab

The Hamburg Living Lab (LL) aims to demonstrate 5G innovations for logistics in the hinterland of the harbour of Hamburg by using the public 5G network operated by Deutsche Telekom. The Test Field for Automated and Connected Driving (TAVF) is located in the northern section of Hamburg, whereas the Kattwyk-Bridge is connecting the most important container terminals with the southern logistics hubs and warehouses including the hinterland goods distribution centres connected to the Port of Hamburg by motorway, rail or inland waterways.

Figure 4 gives an overview of the logistics terminal operation inside the Port of Hamburg. The river Elbe divides the city of Hamburg into two parts, a northern and southern section. Most of the terminals for container handling are in the southern part of the city. For these terminals, the multimodal accessibility for container delivery to the road (motorway) and rail (cargo hubs) are crucial for the overall ports' operation efficiency. This is of special importance as 10,000 TEU container ships nowadays are complemented by Ultra Large Container Vessel (ULCV) transporting up to 24,000 TEU. These mega container ships must be navigated safe and fast along the Elbe river to Hamburg's main terminals, located in the southern part of the city. The challenge for such a sensitive ecosystem is to ensure an efficient organization along the entire multimodal transport chain including water, road, and rail cargo. Therefore, the City of Hamburg published the first Intelligent Transportation Systems

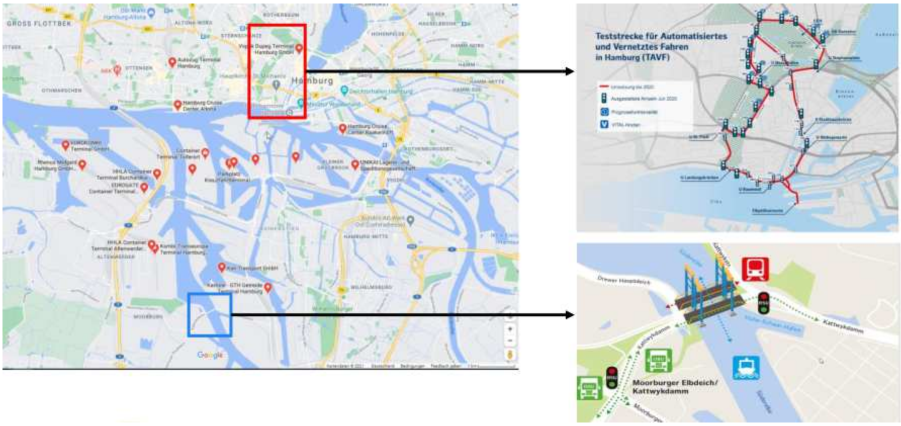


Figure 4 Geographical distribution of Container-Terminals and Test Field for Automated and Connected Driving (TAVF)

(ITS) Strategy in 2016 and ratified it in 2018 for the promotion of logistics and ITS innovation projects.

Within this environment, the Hamburg LL demonstrates, on one hand, how new functionalities of 5G such as MEC and precise positioning can improve the efficiency of logistic operations; on the other hand, it also proves that improved 5G network functionalities such as mMTC and eMBB are essential for any future mobile network application. Furthermore, the Hamburg Living Lab (LL) demonstrates the impact of the 5G GLOSA ATP using the Floating Truck and Emission Data (FTED) which will make available emissions data in the cloud for monitoring purposes, where emissions are calculated based on vehicles/trucks data according to the LCMM methodology[2]. Finally, the Hamburg LL will integrate the EnTruck[3] data using 5G communication. The Entruck platform will be deployed to connect vehicles with the infrastructure and enable a two-channel communication between vehicle and infrastructure. Real-time emission data from truck sensors are transferred to Road-Side Units (RSUs) and traffic controllers calculate the optimum speed for the automated truck platoon in the logistics corridor avoiding stop and go of the truck platoon. The Entruck OBU collects - besides GNSS information - following data in a frequency of 2 Hz from the vehicle for further analysis. More specifically, uRLLC is combined with precise positioning service Skylark cloud-based GNSS corrections service that provides accuracy for the position of up to 0.10 meters. Moreover, the Green Light Optimal Speed Advisory (GLOSA) will help drivers to avoid harsh braking, which is one of the main causes for increased fuel consumption and CO2 emissions. Vehicles/trucks are provided with information on current and predicted traffic lights signal to allow optimizing route planning of automated vehicle manoeuvring across intersections,

[2]The LCMM (Low Carbon Mobility Management) methodology was developed and piloted in the last decade by T-Systems, together with several LSPs in Europe and China.

[3]Entruck is an open telematics and telemetry platform that enables detailed analytic regarding fuel efficiency and wear, based on mobility data of commercial vehicles.

thus saving energy and emissions. More specifically, the optimal speed towards the next intersection is determined, thus avoiding unnecessary energy consuming manoeuvres and reducing pollutants to a considerable degree. Currently, a total number of 26 traffic lights equipped with ITS G5 for traffic management is currently available for test runs.

4.2 Test at Kattwyk-Bridge

Based on the partnership between the (Hamburg Port Authority (HPA) and the T-Systems, on March 10th, 2021 a test has been performed at two selected intersections in the area of the Kattwyk Bridge (Süderelbe). The objective was to test the technologies described on the previous section on a mini-platoon formed by two rental vehicles.

For this purpose, the HPA deploys the so-called ETSI ITS-G5 Standard which allows to add wireless access in vehicular environments (WAVE). More specifically, signals are sent from the flowing traffic by special onboard units at selected intersections and then processed to switch a green time extension at the light signal system. The ETSI ITS-G5 is the IEEE 802.11p, an approved amendment to the IEEE 802.11 standard to enable the networking of vehicle-to-vehicle (V2V or car-to-car / C2C), vehicle-to-road (Vehicle-to-Road / V2R or Car-to-Road / C2R) and vehicle-to-infrastructure (Vehicle-to-Infrastructure / V2I or Car-to-Infrastructure / C2I), know under the term Vehicle-to-everything (V2X). The 802.11p standard used in Green4TransPORT (G4T) which is an innovative project that started in Hamburg to show the practical value of intelligent traffic infrastructure, aimed at improving traffic flow and reducing emissions around the busy Kattwyk Bridge area.

The test drives performed using the FlowRadar of the Hamburg Port Authority (HPA) and the ISO-23795 compatible smartphone app of T-Systems, LCMM, were carried out on Wednesday, March 10^{th}, 2021 between 10 AM and 2 PM. The test was executed along the Green4TransPORT project route of the HPA. For the tests, the FlowRadars were attached to the windshield of two rental cars next to T-Systems' smartphone app and the test was performed along the Roadside Units (RSU) at the Kattwyk Bridge. The driving relationships with the start and end points A, B, C, D are shown in Figure 5 expressing the direction of travel with the start and end points. In total, several journeys along this route were driven by the mini-platoon and stored in the LCMM system of T-Systems for evaluation.

The lead platoon vehicle had a safety distance from the following platoon of approximately one vehicle length (5-10 m). The local traffic management system provided online traffic light data enhanced with a centralized traffic light forecast to enable a GLOSA application. As it is not part of the traffic management centre of the city of Hamburg, it has been deployed on a virtual machine in the cloud.

Table 1 shows round-trip journeys for one vehicle (lead platoon). The trip D-A (in bold), in which the lead vehicle drove without FlowRadar and

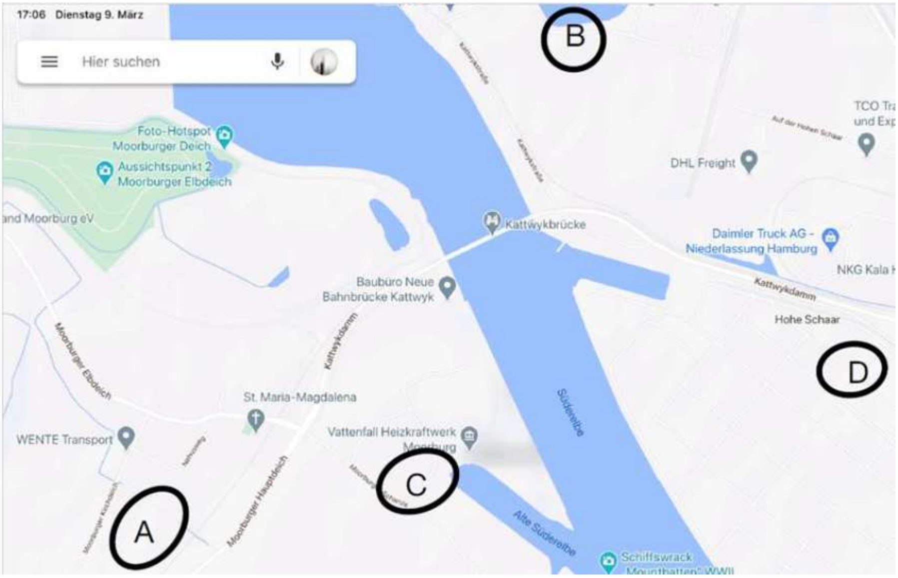


Figure 5 Start and stop measurements along the Kattwyk Bridge

had a significantly higher fuel consumption, is noticeable, from 6.3 liters per 100km to 7.3, which corresponds to an increase of 12%. On all other trips, the difference was not so pronounced.

Table 2 shows the results of the test runs at a glance, with the route drawn reflecting the A,B,C,D outward-and-return relationships shown in Figure 5. As expected, the holding time is very low and the deviation of the speeds shows the longer holding times of the second vehicle. In addition, the values of the Energy Performance Index (EPI) and the Acceleration Index (API) are almost identical for both vehicles, there is a clear deviation in the acceleration and braking of the following vehicle. This leads to the assumption that the follow-up vehicle had to put extra energy into the vehicle due to "catch-up maneuvers" and that platooning could be expected to have different energy values when braking and accelerating when driving manually. Finally, it must be pointed out that a transfer to heavy-duty vehicles results in index values of 1-2 litres per tonne-kilometre, since the mass of a vehicle also significantly affects the inertia forces of braking and accelerating.

4.3 First 5G-LOGINNOV test trips along Hamburg's Test Field for Autonomous Driving (TAVF)

The test drives along the Test Field for Autonomous Driving (TAVF) were carried out on Tuesday, March 23, 2021 and Wednesday, March 24, 2021 from 10 AM to 3 PM. The route was systematically driven in two directions by three to seven rental vehicles in a platoon. The platoon reaches a length of 35m with 7 vehicles. The trips are recorded using the ISO-23795 compatible smartphone APP of T-Systems (LCMM) and the data were stored in the LCMM system

Table 1 Results of the measurements

With Flowradar	
A-D	D-A
Start: 11:25	Start: 11:35
End: 11:31	End: 11:44
4.7 km	5.2 km
6,2 l/100 km	6.3 l /100 km
	Crossroads: 11:38
C-D	D-C
Start: 12:00	Start: 12:07
End: 12:04	End: 12:13
2.5 km	3 km
7.4 l/100km	7.9 l /100 km
Without Flowradar	
A-D	**D-A**
Start: 13:31	**Start: 13:42**
End: 13:40	**End: 13:50**
6.5 l/100km	**5.1 km**
4,7 km	**7.3 l/100 km**
C-D	D-C
Start: 14:18	Start: 14:25
End: 14:22	End: 14:31
2.5 km	3 km
7.5 l/100 km	7.2 l/100km

Table 2 Detailed evaluation of the measurement drives of HPA-FlowRadar and ISO-23795 Smartphone APP of the T-Systems

TripID	acceler. time	Duration	Time	Speed [km/h]	Downtime	EPI [l/100 km*t]	API [kWh/100 km*t]	Segment
1AB	10:56:00	00:06:20	11:03:00	45	00:00:00	3,6	4,5	A-B
2AB	10:56:00	00:06:54	11:07:00	41.2	00:00:04	3,6	5,9	A-B
1BA	11:13:00	00:06:00	11:20:00	42.4	00:00:00	2,8	3,7	B-A
2BA	11:11:00	00:08:31	11:20:00	36.7	00:00:00	3,5	5,4	B-A
1AD	11:24:00	00:06:59	11:32:00	42.7	00:00:02	3,3	4,2	A-D
2AD	11:25:00	00:06:35	11:32:00	44.9	00:00:00	3,2	4,9	A-D
1DA	11:34:00	00:09:28	11:44:00	34.9	00:00:01	3	4,3	D-A
2DA	11:34:00	00:09:56	11:44:00	33.6	00:00:00	3,1	5,2	D-A
1AC	11:50:00	00:07:57	11:58:00	46	00:00:00	3,5	4,5	A-C
2AC	11:49:00	00:10:16	11:59:00	36.8	00:00:29	3,6	5,6	A-C
1CD	12:00:00	00:03:51	12:04:00	40.9	00:00:03	3,1	3,9	C-D
2CD	12:00:00	00:04:04	12:05:00	39.2	00:00:03	3,5	5,1	C-D
1DC	12:06:00	00:06:06	12:13:00	32.3	00:00:01	3,9	4,2	D-C
2DC	12:06:00	00:06:32	12:13:00	30.2	00:00:18	3,9	6	D-C
1AD	13:32:00	00:07:54	13:41:00	37.8	00:00:00	3,4	3,6	A-D
2AD	13:31:00	00:09:11	13:40:00	34.2	00:00:05	3	4,6	A-D

for the evaluation. In order to securely record as much data as possible, the transmission of driving data was monitored in a back office on both days. Each driver was equipped with a smartphone that had the APP and the team of drivers was connected to each other via the meeting function, thus being able to exchange information along the trip. All changes of the platoon were noted in the back office and the drivers were informed of possible errors or problems with data collection.

Figure 6 Test Field for Autonomous Driving (TAVF)

The test of the platoon with seven vehicles was on the route on March 24, 2021 from 1:35 PM to 2:10 PM. At that time, there was relatively heavy traffic on the 7.2 km route. The platoon of seven was in a time window from 1:55 PM to 2:05 PM in heavy traffic on the section Bundesstraße via “An der Verbindungsbahn” to the “Rentzelstraße” intersection.

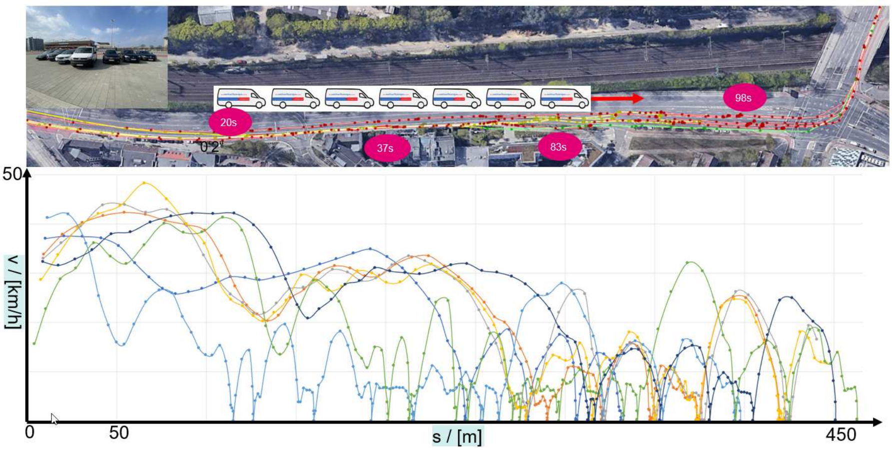
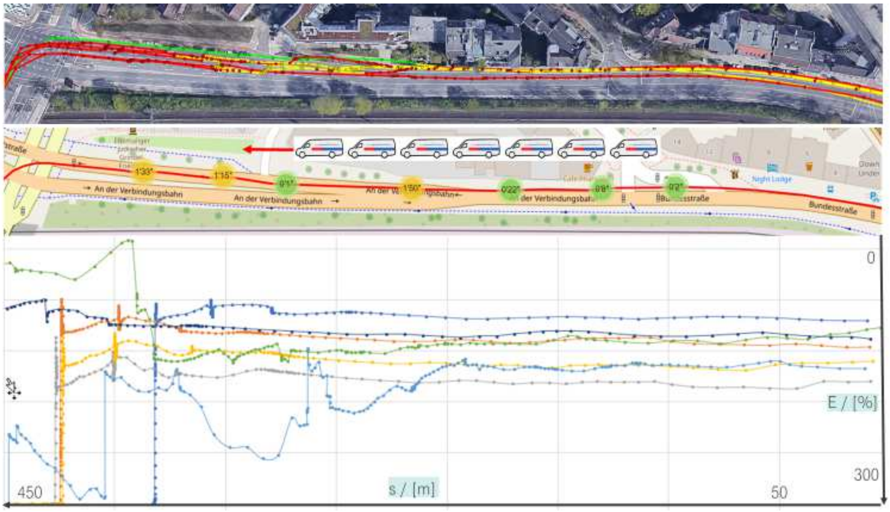


Figure 7 Behaviour of the platoon during traffic conditions

Figure 7 illustrates the behavior of the vehicles on this section and specifically it considers the traffic congestion before turning left. The individual trips of the platoon are indicated with different colors. The colors serve as an indicator of a vehicle's energy requirements based on an analysis of the inertial forces of a moving vehicle. The comparative value of the driving cycle World harmonized Light-duty vehicles Test Procedure (WLTC) (100%), a reference cycle of speeds after which the fuel consumption and CO2 emissions of all engines are measured on a test bench before their approval, and the ISO 23795 method determines the deviation of the inertial forces acceleration, rolling resistance, aerodynamics, incline and standstill in [%] deviation. The WLTC test consists of measuring the speed and acceleration of a vehicle with a frequency of at least 1Hz [Tutuianu et al, 2015]. A chassis dynamometer determines the pollutant emissions and fuel consumption from light-duty vehicles. The procedure has been developed by the UNECE Working Party on Pollution and Energy (GRPE) group.

At the bottom of Figure 7 there is a closer look at the stopping times of a car from the platoon. The diagram shows the speed as a function of the route. There is a stop-and-go phase. The slow-moving traffic on the last part of the section becomes particularly clear. The speed decreases with increasing distance. The fluctuations show the short traffic light phases at the intersection, which often leads to the vehicles stopping.



c v

Figure 8 Energy consumption of the platoon during traffic conditions

Figure 8 shows the section of the indicated trips with the energy values of the vehicles. The diagram outlines the energy in [%] depending on the path. At the beginning of the leg, these values are stable. The closer the platoon gets to the intersection, the more unstable they become. The unsteady noise of the graph of energy illustrates the stop-and-go phase before turning left. More and more energy is always needed to start and a decrease in energy means stopping. In order to smooth out this noise, the traffic light circuit can be improved and signalling information be sent to vehicles platooning in order to stabilize coordination in between the different member and drivers (Level-3) or teleoperated vehicle platoons (Level-4 or Level-5). In all these use cases, it has to be mentioned that only the 5G function of low-latency communication (uRLCC) <50 ms is able to guide the platoon in a safe way to its final destination in the TAVF.

One key element to keep a platoon stable, is the usage of GLOSA in the context of acceleration and collision avoidance. When knowing the remaining time of green to cross the intersection, the lead vehicle of the platoon has to adapt its speed to ensure the platoon will not be disrupted or collide. Therefore, it is necessary to consider the platoon a virtual one-vehicle with length 35 meters and to guide the platoon across the intersection.

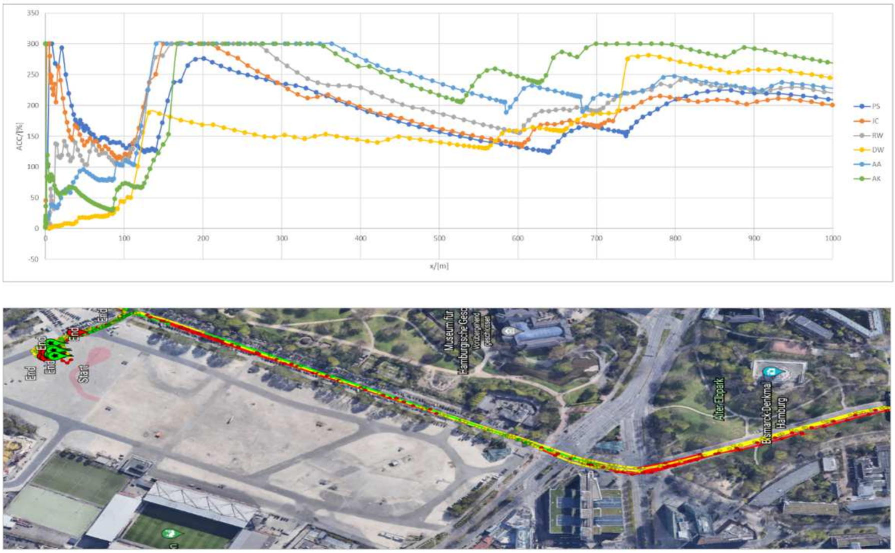


Figure 9 Unstable platoon operation due to high acceleration

Figure 9 shows how the unstable acceleration behavior brings strong fluctuations when comparing lead vehicle and followers. These fluctuations easily lead to disruptive platooning phenomena where the ACC stands for acceleration energy in [%] relative to the WLTP driving cycle. From literature, braking cannot exceed approximately 6 m/s2, therefore Figure 9 indicates that high acceleration energy automatically leads to unstable platoon operation. Any stable and automated platoon will need <50 ms teleoperated driving commands to drive in constant distance and as a virtual “one-platoon-vehicle” where dangerous and harsh acceleration (braking) events increase accidental risks and danger. A fully Level-5 platoon should show harmonized and stabilized acceleration and braking, bringing the range down to approximately

10% changes compared to the approximately 150% changes depicted in Figure 9. The initial tests presented here, will lead to Key Performance Indicators (KPI) field tests showing the different technical components and the 5G capabilities in the context of stable and harmonized urban vehicle platoons using GLOSA, V2X and uRLLC over the Mobile Edge Computing infrastructure.

5 Conclusion

In this work a framework called 5G GLOSA for Automated Truck Platoon has been presented. The results of two test drives performed in the city of Hamburg have shown that 5G GLOS ATP allows to obtain a reduction of fuel consumption above 10%. Furthermore the test have shown that high acceleration leads to unstable platoon operations. The test also showed that latency should be less than 50ms to ensure safety. Finally, Level-5 autonomous drive is expected to further increase the platoon stability. As part of the 5G-LOGINNOV project, further platooning tests will be carried out in Hamburg. In addition to the ITS-G5 journeys on the HPA Green4Transport test track, more test scenarios will be performed on the test track for autonomous and connected driving (TAVF) in Hamburg city centre, using the "cellular V2X" mobile phone standard, known as ITS-G5.

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