Real-world Applications for Connected Vehicle Data

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Abstract

The conventional approach of collecting real world traffic data for management purposes is through stationary detectors, for example magnet field sensors, induction loops, cameras, radar etc. The downside of this detection method is that only momentary information can be obtained and e.g. the behavior of the vehicles approaching an intersection can only be approximated. Vehicle-to-Everything (V2X) communication protocols have a broad variety of applications for traffic management purposes. Through continuous updates, vehicle trajectories can be traced in order to provide optimal routing information for vehicles or to switch traffic lights to green the moment they want to pass an intersection. This paper describes two real-world use-cases for CAM (Cooperative Awareness Message) data provided by connected vehicles (CV) as detector input for traffic management applications. When used in a traffic simulation, detecting vehicles though these messages leads to a more realistic representation of the vehicle's driving behavior. CAMs can be used to place and move CVs inside the simulation of a real-world intersection in Braunschweig with the traffic simulation SUMO (Simulation of Urban Mobility). Furthermore, the paper describes an approach to how these continuously detected vehicles could be further used as control units. Since the positions and speeds of CVs are synchronized with the real-world behavior, they can be used to adjust the simulated upstream movements and positioning of legacy vehicles (LV) to match reality. Until all vehicles are equipped with V2X technology, this approach could enable more realistic simulated traffic flow behavior.

1 Introduction

Cooperative vehicles are an important part of future ITS (Intelligent Transportation Systems). The exchange of information between vehicles (Vehicle-to-Vehicle, V2V) and vehicles and the road infrastructure (Vehicle-to-Infrastructure, V2I, and Infrastructure-to-Vehicle, I2V) is considered a great enabler for increasing road safety and traffic throughput. Thus, connected, cooperative mobility is a highly-active field of research with a great variety of fields of application, some of which are traffic safety, traffic flow harmonization and adaptive signal control.

As V2X-based technologies concerning motorways and trucks have been extensively investigated, research often concentrates on urban contexts. Of course, traffic safety must be ensured in a world of connected - and prospective automated - vehicles. As aforementioned, V2X is considered an opportunity to even increase traffic safety, especially in urban areas where vulnerable road users (i.e. pedestrians and cyclists) are often involved in traffic accidents. Several studies deal with this topic and propose V2X-based systems based on hazard detection and / or automotive assistance [1] [2].

In the field of traffic flow harmonization, dynamic speed advices and platooning are two V2X-based extensions that might help reduce congestion. Platooning minimizes gaps between vehicles and thus reduces passing times of vehicles over intersections. Speed advices can be used to let vehicles pass an intersection without stopping, leading to reduced time losses and emissions due to braking and accelerating [3] [4] [5].

Along with platooning, adaptive signal control in urban areas is another important field of application for V2X technologies. Several algorithms that optimize phase sequences and phase durations based on vehicle position data provided by V2X have been developed and significantly reduce vehicle waiting times compared to conventional adaptive control methods [6][7].

The aforementioned position data of vehicles is transmitted as Cooperative Awareness Message (CAM). This is a standard defined by the European Telecommunications Standards Institute (ETSI). CAM is a basic set of information to make other connected traffic participants and the infrastructure aware of the presence of a traffic object. This message type contains for example information about the object's type (e.g. passenger car, truck, bus etc.) and its current position, heading and speed. Typically, CAMs must at least be broadcasted with 1 - 2 Hz to enable vehicle-vehicle and vehicle-infrastructure cooperation and to avoid crashs [8].

The fact that CAMs provide information about the type, the position and the speed of an object on a regular basis qualifies them as a data input for traffic control methods. Conventional vehicle detection is done through static detectors, e.g. induction loops or magnetic field sensors. These detectors provide data at the moment a vehicle disturbs their magnetic field. This detector data has been used before to insert traffic demand into a traffic simulation coupled with a traffic light controller by adding a vehicle with the maximum free speed at the detector position. The disadvantage of this approach is that the downstream traffic flow behaviour, for example the approach of a red traffic light, can only be approximated by the underlying model. CAMs however, close this data gap since they continuously provide position and speed information which can be fed into the simulation.

In section 2, the approach on processing CAMs will be described. Afterwards, two applications of this algorithm are presented that improve simulated traffic flow behaviour at low penetration rates of CAM sending vehicles. Section 3 describes the real-world test of this approach on an intersection in Braunschweig, Germany. In section 4, summarizes the results and gives a short outlook on future activities.

2 Methodology

The method of processing CAM data in a traffic simulation presented in this paper consists of a main part and two extensions. The main part describes how vehicles from various data sources (i.e. CAMs and static detectors) are inserted in the same simulation, the extensions apply the additional data obtained through CAMs to influence the simulated traffic flow.

The procedure of inserting CAM-detected vehicles into a traffic simulation is described in Algorithm 1. The vehicles' driving behaviour should be determined only by position updates they provide, not by the internal logic of the traffic flow model. Thus, all CAM vehicles that were inserted in the previous simulation step need to be removed from the simulation. The removal of the CAM sending vehicles also might be necessary due to data security issues with V2X data. Since it would be possible to re-construct single vehicle trajectories on intersections from their CAMs, a possible solution might be to introduce short-term changing identifiers (as proposed in [11]). In case such measures are taken, the deletion of previously detected vehicles

Algorithm 1 CAM-based vehicle insertion

step + 1
for all CAM_sending_vehicles inserted in *step* − 1 **do**
  delete_vehicle()
end for
parse_CAMs()
for all CAMs received **do**
  if type not RSU **then**
    insert_vehicle()
  end if
end for
insert_vehicles_from_static_detectors()

would be unavoidable.
In the next step, the CAMs received in the current step are parsed. The result is a list of attributes that describe the vehicles' states:

- **id**: A unique identifier for the vehicle
- **type**: The vehicle type, i.e. passenger car, taxi, bus etc.
- **coord**: The position of the vehicle (lat, lon)
- **speed**: The current longitudinal speed of the vehicle

For each CAM, a type check is made since the definition of CAMs does not only apply to moving objects such as passenger cars but also to Road-Side-Units (RSU). This check ensures that only moving objects are inserted. The vehicles are inserted at their respective positions and assigned the speed values they reported. Afterwards, conventional vehicles that were detected by static detectors (e.g. induction loops) can be inserted. It is important to insert the vehicles in this order since otherwise, they would be detected as conventional vehicles, leading to a loss of information and potentially an over-estimation of traffic demand.

Apart from just using CAMs as additional data input, they can be used to adapt the behaviour of the conventionally detected vehicles. As shown in Figure 1, a CAM vehicle is inserted into the simulation with a reported speed of 40 km/h. Upstream, a LV is inserted at the detector position with a free speed of 50 km/h. Without the presence of the CAM vehicle, the LV would drive downstream the road with free speed. Due to the reduced speed of the CAM vehicle, the LV needs to adapt its speed to 40 km/h in order to avoid a collision. This speed adaption of the simulated vehicles leads to a more realistic representation of the edge's traffic flow. The adaption continues upstream as more LVs are inserted.

Another possible field of application of CAMs in a traffic simulation is to use them as detector vehicles for queue lengths in front of a red traffic light (see Fig. 2). In the following, two possible applications are presented. The first approach is an application of an approximation method described by Priemer and Friedrich [9]. A downside of contemporary detection is that sometimes, vehicles passing detectors are not detected which leads to underestimation of the traffic demand. When running an adaptive control algorithm, this can lead to inefficiencies or in the worst case to extremely high waiting times if it occurs on approaches of an intersection with an overall low demand. From the stop position of a CAM vehicle we can obtain the minimum length of the queue. If a gap larger than the length of a vehicle occurs between the CAM

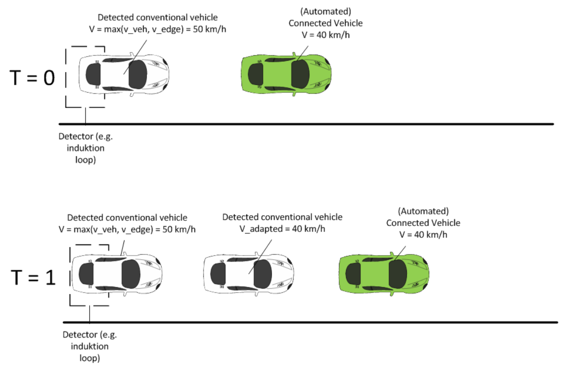

Figure 1: CV as detector vehicle in a free flow traffic situation.

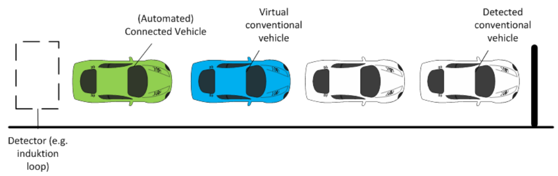

Figure 2: CV as detector vehicle in a queue in front of a red traffic light.

vehicle and the last detected LV or the stop line, we can assume that there could be another vehicle which was not detected previously. By measuring the gap between the CAM vehicle and the last LV in the queue and assuming a standard length per vehicle plus minimum gap to the preceding vehicle, "virtual LVs" could be added to match the demand on the queue. The number of virtual vehicles to be inserted would be $l_{queue\_gap}/(l_{vehicle} + l_{min\_gap})$.

The second approach in the field of queue length correction would be to remove vehicles that passed the traffic light in reality, but did not in the simulation. In reality, drivers sometimes pass traffic lights that just switched to red, either because they were not able to brake or they did not want to stop because of subjective time pressure. However, in the simulation these vehicles in general do not pass red traffic lights because they strictly obey the set of traffic rules given to them [1].

Note Figure 3 for the description of this approach. In the real world, a LV passed the traffic light shortly after it turned red, the CV stops in front of the traffic light and sends its position information to the simulation. In the simulation, the underlying rules forced the detected LV stopped in front of the red traffic light, the CV is enqueued behind it. However, the position sent by the real-world CV is the same as the position of the LV that (in reality) already passed the intersection. This means, if the position provided by a CV is the same as the position of a simulated LV, we can assume that the LV already passed the intersection and remove it from the simulation.

Both applications work with low penetration rates since only one CV is needed per approaching lane. Thus, we have one detector vehicle per lane with which traffic flow and queue lengths could be adjusted. The approaches presented here could be part of a correction module for traffic state estimation until the penetration rate of CVs allows a more complete overview

[1]This behavior is actually configurable in many traffic simulations like SUMO, but the default setting is that vehicles do not pass red traffic lights.

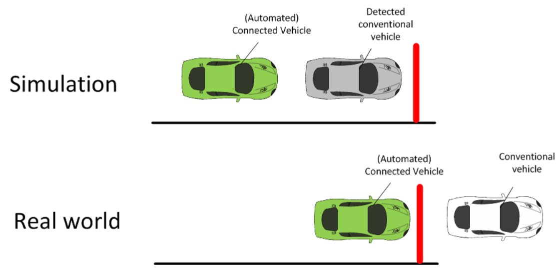

Figure 3: CV as detector vehicle in a free flow traffic situation.

of situations at intersections.

3 Application

3.1 Tostmannplatz, Braunschweig

The first test of the insertion method took place at the real-world intersection Tostmannplatz in Braunschweig, Germany (see Fig. 4) in the context of the project MAVEN (Managing Automated Vehicles Enhances Network, funded by the European Commission, see http://maven-its.eu). Only the insertion of vehicles based on CAMs was tested, not the applications (speed adaption and queue correction).

Figure 4: Aerial view of Tostmannplatz. ©Google Maps

The intersection is part of AIM[2], a test bed for automated and connected mobility in Braunschweig operated by the DLR. It was already equipped with an RSU (e.g. Car Communication Unit (CCU) and Application Unit (AU)) that enable V2I communication. In the DLR project VITAL, the intersection was equipped with additional infrastructure to enable the operation of DLR traffic light control algorithms [10]. The new infrastructure consisted of two main components:

- **Industrial computer**: Running a SUMO simulation coupled with the AGLOSA algorithm (see [7]). The computer is connected to a traffic light controller that reacts to phase requests sent by the algorithm. In the other direction, the traffic controller passes its current phase to the simulation to synchronize the simulated and the real traffic light states. Also, information about detected vehicles is given into the simulation to generate a simulated traffic demand on which AGLOSA can plan.
- **Magnet field sensors**: Detect passing vehicles and transmit this information wirelessly to the traffic controller.

The insertion of LVs is done through the data provided by the magnet field sensors. This still is the main data source for inserting vehicles into the simulation. The insertion of vehicles by CAM is an extension to this functionality. To enable the processing of V2X information, the industrial computer was connected with the AU. Thus, incoming CAM messages can be passed to the simulation where the insertion method processes them into simulated vehicles.
The test of the insertion method took place during two separate test events in December 2018 and January 2019. During these events, the AGLOSA algorithm controlled the traffic light over the course of four hours. Two research vehicles were making test drives on Tostmannplatz broadcasting CAMs. These messages could successfully be processed into simulated vehicles and were taken into account by AGLOSA when planning the next phase sequence. Since the vehicles drove only in the main direction (northern and southern approaches) where more than one lane can be chosen by the simulated vehicles, the effect of the speed adaption could not be measured since the simulated vehicles took over the slower CAM generated cars.

3.2 Project SIRENE

The research project SIRENE (Secure and Intelligent Road Emergency Network, funded by the BMVI (Bundesministerium für Verkehr und digitale Infrastruktur, Federal Ministry of Transport and Digital Infrastructure), see `https://sirene.ifak.eu/`) yields another field of application. The overall aim of the project is to reduce travel times for emergency personnel like fire brigades and police (see Fig. 5). This is crucial when facing hazardous and unpredictable events like fires, accidents, demonstrations and major indicents in general. Especially the coordination of large forces, multiple deployment sites and dense traffic on the way to the emergencies are major challenges for the emergency personnel. Sirens and emergency lights are still considered the most effective tools for clearing the way of emergency vehicles. Currently however, many new technologies that can assist these established tools digitally were developed. For instance, many cities operate connected traffic lights that enable an intelligent traffic management and a faster reaching of the deployment site. Furthermore, the emerging V2X technologies have much potential for interactions between emergency vehicles and their surroundings. Regardless the technology used, the operation of communication technologies in the field of security and

[2]Application Platform for Intelligent Mobility, https://www.dlr.de/ts/aim#gallery/25304

emergency agencies requires to be secure and failure-free.

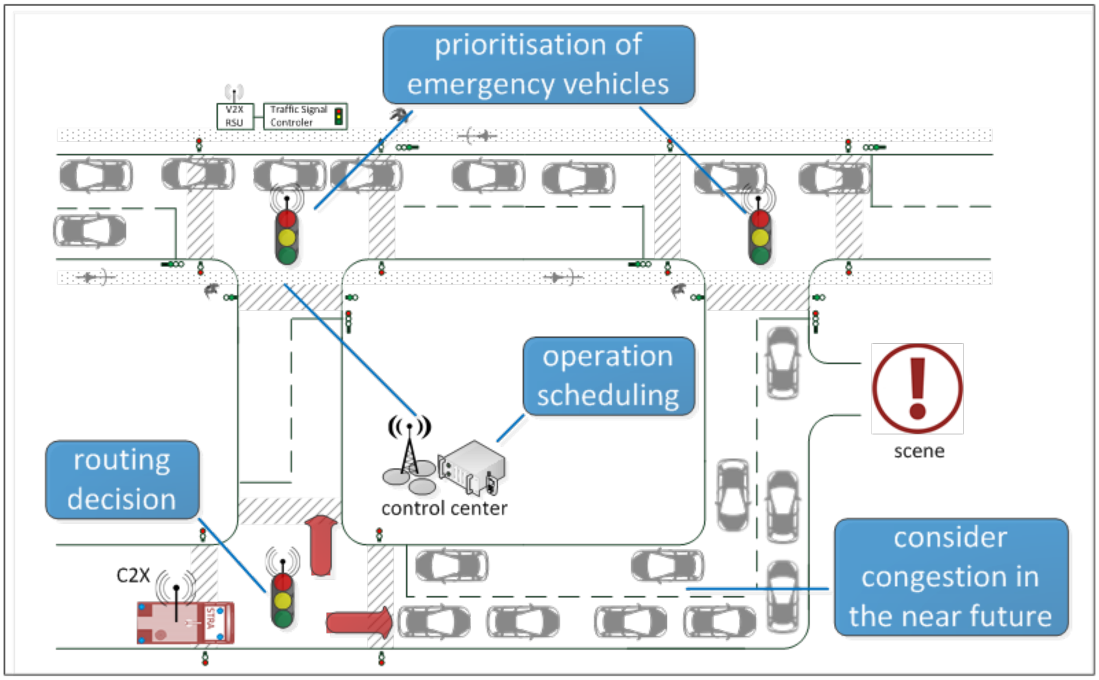

Figure 5: SIRENE system overview. Source: Ruppe, Sten and Nippold, Ronald and Trumpold, Jan (2018) SIRENE - Secure and Intelligent Road Emergency Network. SUMO User Conference 2018, 14.-16. Mai 2018, Berlin, Deutschland

Apart from the mere acceleration of emergency vehicles through an optimal routing, two approaches for prioritization of emergency vehicles are analyzed in the project SIRENE. The first approach extends an already existing centralized approach in which the traffic server of a city is connected with the traffic lights and the computer-aided dispatch system of the fire brigade. In the second approach the prioritization is realized decentralized through V2X technology. Therefor, authorized vehicles request a prioritization through V2X messages sent to computers at traffic lights. In the test field AIM in Braunschweig, these approaches will be installed and tested. Currently, four vehicles of the Braunschweig fire brigade are equipped with On-Board Units (OBU). The OBUs send their current positions and in the near future segments of their planned route to the Road-Side Units (RSU) of a traffic light. An industrial computer processes the incoming messages, verifies the prioritization requests and forwards them to the traffic light controller.
For both prioritization approaches, the current traffic situation at the intersections along the vehicles' routes is highly relevant. At the moment, the situation is measured through local sensors like induction loops or infrared cameras. In the context of this project, the emergency vehicles used V2X messages as a replacement for detector data, so no additional detection was used. The test was performed at the intersection Rebenring / Hagenring in Braunschweig. Unfortunately, the integration of the prioritization was not finished until the test. Thus, only the detection of traffic through real V2X data could be performed. In Fig. 6, the intersection and two data sets of recorded data are displayed. The lower speeds of the yellow data set in the

middle of the intersection indicate a higher traffic load or the presence of a queue the emergency vehicle has to seep through. Apart from that, both vehicles could pass the intersection with full speed.

(a) Test intersection Rebenring / Hagenring in Braunschweig with recorded positions of two emergency vehicles.

(b) Detail view of the test intersection. The annotations at the points correspond to the momentary speed of the test vehicles.

Figure 6

4 Conclusion

This paper presented a methodology that uses CAM data provided by connected vehicles to measure the overall traffic situation on urban roads and intersections. In the first application, it was shown on a real-world intersection that it is possible to feed V2X information into a traffic light control algorithm that already uses static detector information and to enrich the data base of the optimization procedure. Yet, the simulated vehicles in the test did not adapt to the speed of the CAM inserted vehicles since they were able to take over. This could be bypassed by driving CAM sending vehicles on single-lane approaches of the intersection or by ensuring a higher penetration rate of CAM sending vehicles. The second application used speed information provided by emergency vehicles to get a rough first idea of the current traffic state at an intersection. Due to a lack of measurements, this test is far from being representative but it gives a first idea of the possibilities that V2X data offers.
Future work will focus on implementing and testing the speed adaption and queue length applications and measure their influences on the quality of the traffic flow.

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