Collaboration over IEEE 802.11P to enable an Intelligent Traffic Light Function for Emergency Vehicles

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***Abstract*— With the advent of cooperative automated functions a host of novel functions becomes feasible – cooperative driver assistance systems (CoDAS). We present an example for a novel collaborative vehicle-2-infrastructure interaction with the "automated emergency vehicle green-light" (AEVGL) function. In our approach we combine traffic light infrastructure with Dedicated Short Range Communication (DSRC) over IEEE 802.11p to address a serious issue: accidents containing emergency vehicles at intersections. In AEVGL we utilize communication to preemptively switch traffic lights to red for crossing traffic to allow safe passage of the approaching emergency vehicle even in low communication penetration scenarios. This function can serve as blueprint for other novel lightweight CoDAS functions with a very specific scope.**

***Index Terms* — emergency vehicle; cooperative systems; intelligent traffic light; 802.11p; CoDAS**

I. Introduction

Cooperative systems using dedicated short-range communication (DSRC) are set to be introduced in this decade [1] and will allow a host of functions. First functions will include warnings of road-works ahead and "floating car data" in Europe [2] and safety-related functions in the US [3]. Further functions will likely align to those tested in the largest recent field operational trials "Safety Pilot" and "DRIVE C2X" [4], [5]. All of these functions, however, are only providing information and warnings to the driver and do not include any automated actions.

The field of automation has long been a focus of advanced driver assistance systems (ADAS) and more recently in high-automated "pilot" functions and autonomous vehicles. By combining the information wealth of communication and the intervention capabilities of ADAS, existing functions can be augmented and novel functions can be created. This field of "cooperative driver assistance systems (CoDAS) is therefore in the scope of current research in projects such as "Autonet2030" and others [6]. We have presented a first overview of conceivable functions along with a classification method in [7]. Focus in current CoDAS functions research is often on vehicle-to-vehicle collaboration, as this is an obvious target. Infrastructure is therefore often reduced to "information source" and "information sink". In this paper we present a new approach to collaboration with infrastructure elements. We exemplify along a collaboration of emergency vehicles (EV) with traffic light controllers.

We have chosen this very specific function to provide an example for vehicle-2-infrastructure collaboration in CoDAS – requiring active automated intervention in both communication parties and thus a high level of cooperation capabilities. The function itself can serve as blueprint for other novel CoDAS functions. Nonetheless, it addresses a serious background: Studies have shown, that emergency vehicles while in emergency operation have a significantly higher risk to be involved into traffic accidents [8]. The most common cause for accidents is right-of way violation by other traffic participants at intersections [9]. Additionally, the severity of crashes is significant due to high speed of involved vehicles.

In our exemplary function, we utilize collaboration over 802.11p communication to allow intersections to detect approaching emergency vehicles and adapt their timing to allow for safe passage. We have implemented and tested three strategies:

- All red: upon approach of the EV, the intersection controller sets all traffic lights to red. This approach is most feasible in low traffic scenarios, when no or light queues are present.
- Red flashing: similar to "all red", but with flashing lights to get additional attention of approaching vehicles.
- EV green: The traffic lights on the direction of approach for the EV are timed in such a manner, that the EV gets an automatic green-light phase. Thus, queued traffic ahead of the emergency vehicles is freed to move, making it easier for the emergency vehicle to pass. This approach is feasible for high traffic scenarios, when an "all red" strategy would block the roads.

Since testing in real-world operation requires active interference into a traffic light controller, we have initially tested the function in a physics simulator ("Phabmacs") in the VSimRTI suite [10]. Since the possible impact of this function is highly reliant on human factors (i.e. perception of the red light in comparison to perception of the emergency vehicle by crossing traffic), the conclusion taken from simulation is regarded as technological proof-of-concept. We encourage other parties to implement the AEVGL function into field operation trials to evaluate possible impact. Furthermore, we hope to give a blueprint for comparably simple but efficient collaborative functions with this work.

This paper is structured into five chapters. We follow up to the introduction with a survey of comparable approaches in chapter two. In chapter three we present the developed concept – we distinguish between function concept and communication concept. We present our implementation in chapter four and finish with the concluding chapter 5.

II. Comparable Approaches

Communication at intersections is an ideal scenario. Intersections often feature obstructions by vegetation or buildings, making it hard for drivers to view crossing traffic. Furthermore, most in-vehicle sensors such as radar, lidar or cameras are also affected by these obstructions.

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Manufacturers recently started to install sensors in the vehicle front facing sideways to implement first intersection accident avoidance [11].

Radio-waves are also affected by obstructions, however, trails have shown acceptable range even in high obstruction scenarios [12]. Intersection collision avoidance in functions “Intersection Movement Assist” and “Left-turn Assist” was one of the functions under test in recent FOT “Safety Pilot” in the USA [4]. Previously, German FOT sim^{TD} tested a similar function with the “Kreuzungsassistenz” (Intersection Assistance) function [13]. Le et. al. give an overview on previous similar functions in [14].

All of these functions suffer from one of the basic problems in communications – the penetration rate. Therefore, any intersection prevention assistance based on transmitted locations of other vehicles is only functional in high-penetration scenarios.

An alternative approach is to communicate with traffic infrastructure: in these approaches, the intersections themselves are equipped with sensors to detect approaching vehicles and use vehicle-2-infrastructure communication to warn communicating vehicles of possible accidents. This approach performs better in low-penetration scenarios, as all vehicles can be detected by the intersection – regardless of their communication capabilities. The obvious downside is a higher investment into infrastructure. This approach was for instance tested in the PATH project [15].

Efficiency-related communication with intersections was developed and tested in the sim^{TD} project and in DRIVE C2X with the “green-light optimized speed advisory (GLOSA)” function [5]. Here, an equipped traffic light would broadcast its signal-phase and timing to allow approaching vehicles to adapt their speed to pass the light at a green phase.

The concept of automatically adapted speed to optimize intersections is known as the “automated intersection”. These (theoretic) approaches optimize intersection throughput by dynamically allocating intersection space slots to oncoming vehicles. Approaches can be infrastructure-based of vehicle-2-vehicle based, with and without support for non-equipped vehicles and with support for platoons of vehicles [16]–[19].

Emergency vehicles have been addressed in the DRIVE C2X project with the “approaching emergency vehicle (AEV)” function. Here, these vehicles broadcast position, direction and speed as well as information about the usage of emergency signal lights. Thus, other equipped vehicles can be warned and drivers advised. One of the investigated use-cases was a warning at intersections.

Fig. 1. GLOSA and AEV testing in DRIVE C2X (© Fraunhofer FOKUS)

III. Function Concept

Our approach is in parts similar to some of the presented functions from chapter two: we utilize communication from the emergency vehicle. Instead of warning other vehicles directly (and thus being reliant on high penetration) we utilize the traffic lights to adapt timing to give approaching emergency vehicles an automatic green light (a direct inverse to GLOSA). This has the additional benefit of providing a very clear and intuitively understandable message to any crossing vehicles – a red traffic light. The function can be enabled with low equipment cost for the emergency vehicles, traffic light infrastructure and other participating vehicles.

A. *Communication concept*

Collaborative systems require communication between the involved participants. In the case of intelligent traffic lights, these are the emergency vehicles, traffic lights and other equipped vehicles. We built our example on standard ETSI ITS G5 messages with the extension of Collaborative Maneuver Messages (CMM) [20]. Emergency vehicles like other vehicles send out Cooperative Awareness Messages (CAM) [21] periodically at 10 Hz. They contain information about the position of the vehicle, but also sensor information such as the current speed. Additionally emergency vehicles send the status of the siren and the emergency lights.

Thus the other vehicles and also the traffic light will know, whether there are emergency vehicles in the surrounding and what their current status is. The traffic lights on their part also send out messages, namely Signal Phase and Timing (SPAT) and Topology (TOPO) messages [22]. TOPO messages describe the structure of an intersection. They contain all the traffic lights of the intersection. For each light there is a set of lanes for which the traffic light is relevant. The lanes are described by an approach trace. With the SPAT messages for each traffic the duration and signal state of the current and subsequent phases are transmitted. The traffic lights in the SPAT messages can be assigned to lanes in the TOPO message by a unique identifier. The traces are evaluated by the vehicles that receive the messages. If the traffic light is relevant, i.e. when the vehicle is driving on the trace and is close enough to the traffic light, the GLOSA application will generate an appropriate information for the driver based upon the SPAT messages.

Current communication messages in ETSI ITS G5 are unidirectional with no direct response foreseen by message receivers. We utilize the Collaborative Maneuver Message (CMM) [20] protocol to extend vehicle-2-infrastructure communication with persistent session-based communication capabilities. Therefore, the traffic light as well as the emergency vehicle are capable of joining a “CMM session”.

This session container serves as dual purpose. First, it is an identifier of the type of cooperative function performed by the participants along with their role to be held. This role serves as non-formal guideline of behavior in a CMM session. I.e. a platooning function can have roles “lead”, “follow1”, “follow2” and so on. Roles are initially proposed in the session invite, and can be re-negotiated in further state change requests. In AEVGL only two roles are contained and serve obvious purposes: “intersection” and “emergency vehicle”.

Secondly, the session serves to synchronize the current distributed state of the function. In distributed collaborative driving functions it is eminently important, that all participants hold a common understanding of the current function state and therefore act in a synchronized manner. To this regard, the session enables a distributed state machine. Transitions between states are conducted by a request-response pattern – since AEVGL is designed for only two participants, therefore any decision has to be unanimously taken (CMM also supports majority votes). The state in conjunction with the role defines the expected participant behavior.

In AEVGL the session is established on initial communication range by the EV with an invite message. Traffic light controllers can chose to accept or decline the message. Once established, the session reflects the progress of approaching the intersection, allowing both participants to hold a synchronized situational understanding as well as to negotiate collaboration. In our example, three phases are passed. Each of these is entered with a request message, upon which all session participants have to acknowledge. This process along with synchronization is handled by the CMM framework. In AEVGL the function will pass three states: “initialize”, “approach” and “pass”.

In “initialize” a collaborative session is agreed upon. The participants chose roles (in AEVGL these are obvious: EV and Traffic light). Once the EV passes a certain time to arrival, a request is issued to enter the “approach” phase. Here, the intersection aligns the signal phases to ensure a controlled passing of the EV. Finally, once the EV is close to the intersection, the “pass” phase is entered. In this phase a final commitment is given to the EV to ensure a safe passing. Similarly, the traffic light will lock the corresponding signaling until the EV has passed. After the EV has left the intersection, a “Leave” message is sent to dissolve the session in a controlled manner.

Of course, security is adamant in this function. Cooperative communication over 802.11p is an open network, and thus vulnerable to attacks. We utilize a PKI key structure to allow signing of messages. It is necessary for traffic light controllers to hold a-priori knowledge of registered EV and their public keys. The controller will then only react to messages sent by valid official emergency vehicles.

Additionally, distributed consensus in wireless ad-hoc environments presents a huge challenge [23]. To this avail, the CMM protocol implements a synchronization layer, which is based on a derivate of the Paxos algorithm [24].

However, since ultimately, no consensus can be guaranteed, CMM utilizes timeouts to notify the application of failed synchronization. In AEVGL, this timeout is registered and the traffic light is reverted to normal mode of operation.

B. *Function concept*

In our function two ITS stations are collaborating: the ITS Vehicle Station (the emergency vehicle) and an ITS Roadside Station (in the traffic light controller). Both stations have a very similar architecture and are thus discussed together.

In our example function no automation is utilized in the EV, however the function could in future be paired with longitudinal control to optimize approach speeds for EVs. For automation an additional integration unit (IU) must be integrated into the architecture. The IU is responsible for all driving-critical tasks, which will double-check all received input on possible accident risk.

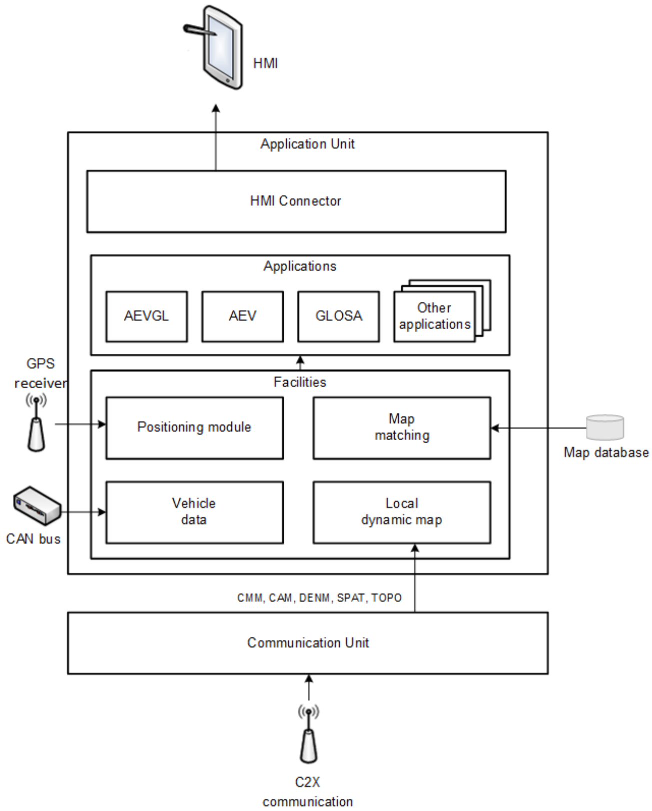

Fig. 2. System architecture

The system architecture of an equipped vehicle can be seen in Figure 2. The vehicles are equipped with an Application Unit (AU) and a Communication Unit (CU). AU and CU are connected with several external sources. The major enabler for collaborative functions is Car-to-Car and Car-to-Infrastructure Communication (C2X).

The Communication Unit receives the different message types (CMM, CAM, DENM, SPAT and TOPO) and makes a relevance check, i.e. whether the vehicle is in the relevance area of the message and whether the message is not outdated. If the message is relevant it is stored in the Local dynamic map (LDM) where it can be accessed by all functions.

More input sources are connected to the Application Unit. The GPS receiver is essential, because most cooperative functions are based on the location of the vehicle. Also the CAN bus is accessed in order to retrieve relevant car data. For the emergency vehicle this is especially the status of the siren and the emergency light.

The cars also have a map database installed. Thereby the vehicle position from the GPS receiver can be improved by map matching. Moreover trace matching for traces received over TOPO or DENM messages can be performed in order to check if the message is relevant for a specific application.

The applications can make use of these facilities. E.g. the GLOSA application can check with help of the vehicle position and the messages received from traffic lights, if it must inform the driver about a traffic light ahead. Warnings are displayed over the HMI.

Each traffic light controller is equipped with a Road Side Unit (RSU), which has a similar architecture. The external components HMI, GPS receiver and CAN bus and their counterparts in the facilities stack are missing. Rather a fix position that is more precise is used. Besides the sender for SPAT and TOPO messages other applications can reside on the RSU, e.g. Traffic Jam Ahead Warning or Weather Warning.

IV. IMPLEMENTATION AND SIMULATION ENVIRONMENT

Our collaborative application is one of the few applications that has the main part of the function logic running on the RSU. The reason for this is that it does not generate a direct output to a user via HMI. Rather it manipulates the phases of a traffic light connector connected to the RSU. However the function is dependent on the sending part of the AEV function in the emergency vehicle. When the siren or the light bar is turned on in the emergency vehicle, the AEV function will set the corresponding flag in the CAM messages.

Once the CAM messages from an active emergency vehicle are received by the traffic light, the relevancy of the emergency vehicle is checked. First a rough estimation is made by the linear distance of the vehicle. Only emergency vehicles within 800 meters from the traffic light are considered. After that, a map matching of the vehicle position is performed. With the topology information of the traffic light, the function can detect if the emergency vehicle is on an ingress lane to the traffic light. If this is the case based on the speed of the vehicle included in the CAM message, a Time-To-Arrival (TTA) to the traffic light is calculated and the CMM session is established. The initial phase is “initialize”.

When the TTA falls below a certain limit a request is sent to enter the “approach” phase. In this phase, AEVGL will alter the traffic light phases. In our experiments we utilized a threshold of 30 seconds. In the first scenario, the application changes the signal phases for all traffic lights to red. Therefore they will first turn to yellow and then to red after five seconds. When a traffic light is already red, no action is required.

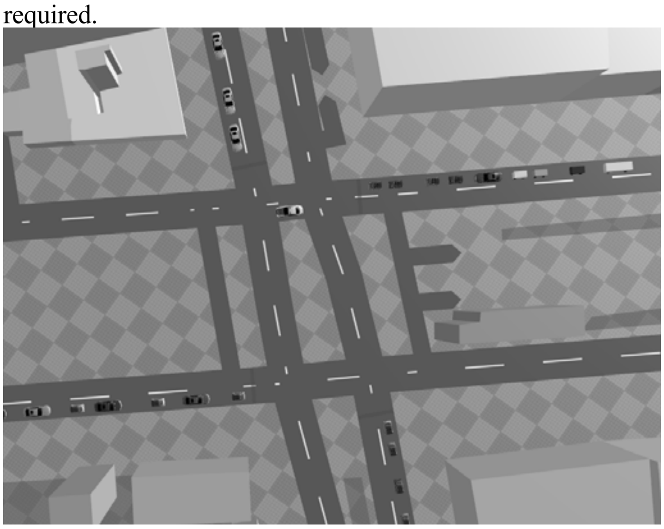

Fig. 3 Screenshot of the simulator implementation with scenario 1

In the second scenario a similar strategy is applied. The signals of all lanes are affected again. However instead of turning to yellow and red for the lanes that do not yet have a red phases, on all lanes a red flashing light is started immediately. This has the advantage that drivers will react instantaneously and that they will also know that there is an exceptional situation.

In the third scenario, the traffic lights in direction of the EV are changed in a different way. In case that they are not green already, they will be set to green with a possible short yellow phase before. With this change, the vehicles driving alongside the EV will continue moving and hence will not block the way of the EV.

Due to the change of traffic light phases all vehicles are stopped to make way for the EV, whether they are equipped or not. Hence the GLOSA function is not required in the vehicles. However there is an implicit connection to GLOSA. As GLOSA sends out the current and upcoming traffic light phases periodically, all equipped vehicles will be informed about the traffic light change automatically.

Furthermore, all vehicles that are not equipped will also benefit from the applications as the actual traffic light indicate them to stop. The traffic light controller will then send a request to enter the “pass” phase. This signals to the EV, that it can pass the intersection in a safe manner.

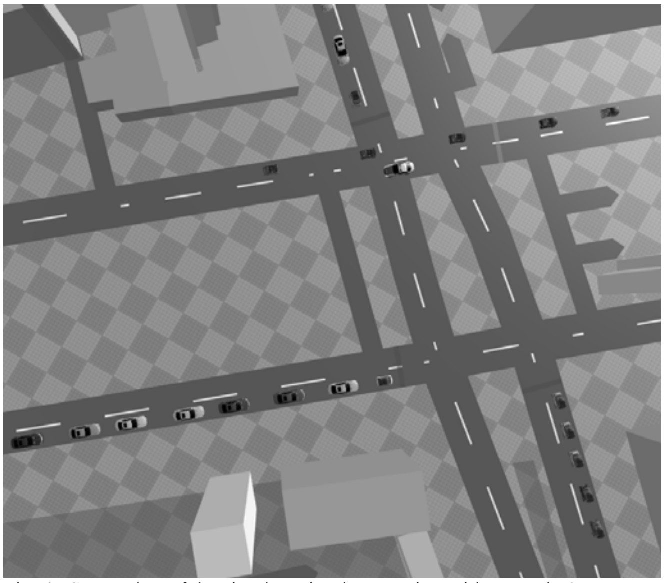

Fig. 4. Screenshot of the simulator implementation with scenario 3

When the emergency vehicle has passed the intersection the relevance check of the RSU will detect that the EV is no longer approaching the traffic light. After a timeout of 10 seconds the normal traffic light phases are applied again and the CMM session is resolved with a “leave” message.

Testing the application in a real world scenario would require to equip a vehicle with emergency lights or a siren and to interfere in the control of an actual traffic light. As we could not yet arrange this on a public road, the function was implemented in the “Phabmacs” vehicle simulator. Phabmacs can simulate a large number of vehicles with realistic physical features in a traffic scenario.

The implementation of scenario 1 within the simulator is shown in Figure 3. The traffic light for all lanes shows a red signal. Thus the intersection is cleared so that the emergency vehicle can pass the intersection without risk. As it can be seen, all vehicles in the direction of the EV give way to it. However at a higher traffic load, this might be more difficult and it take more time.

Hence in scenario 3 the lane of the EV will get a green phase until the EV has passed. The vehicles on all other lanes have to stop so that they don’t block the EV. In Figure 4 the scenario 3 is shown in the simulator environment.

V. CONCLUSION AND OUTLOOK

In this paper we have presented an example of a collaborative infrastructure to vehicle function. Collaborative automated functions such as this offer high potential for safety, comfort and efficiency improvements, but require sophisticated communication and function design to ensure safety and security. To this avail, the CMM protocol was used in this paper.

The “Approaching Emergency Vehicle Green-Light” (AEVGL) function addresses a serious issue: accidents involving emergency vehicles at intersections. Instead of directly warning other cooperative vehicles (and thus being reliant on high penetration), we show how the intersection controller can directly interact with the emergency vehicle.

We utilize a collaboration protocol, which amends ETSI ITS G5 – the cooperative maneuver messages (CMM). This protocol allows the EV and the intersection to join a common synchronized session and to negotiate passing of the EV. The session allows a common consensus on state of approach of the EV. The traffic lights are then switched to red for all crossing traffic to prevent any intersections. Furthermore, a mode for high traffic load (switching lights in EV direction to green) and one for low traffic load (all lights red) are presented.

The Phabmacs simulation environment was used to implement a proof-of-concept simulation. In further steps we hope to adapt the function to the TEAM framework [25] and to test it in the Berlin test lab under real conditions. Further research should be conducted into human interaction to evaluate impact of the three different strategies onto driver behavior.

Further possible steps are an integration into higher modes of automation for both the EV as well as for other traffic participants.

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