SHUTTLES & CO: INFLUENCING AUTONOMOUS SHUTTLE BUSES USING V2X COMMUNICATION

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ABSTRACT

Currently, there are only a few technical aids or even control methods to accelerate autonomous buses in urban traffic or to provide them with an extended green phase. This is necessary because their speed is very different from other road users. Communication between autonomous buses and the infrastructure using vehicle-to-everything (V2X) communication is already possible and well researched. It is not yet supported by many manufacturers of the control units and also manufacturers of vehicles. In the project, we have researched the development of a new traffic light signal system (LSA) control procedure with innovative traffic light system communication and detection technology and also implemented it in real traffic. The results from the research can currently already be used for small vessel sizes. The offer can be extended by possible on-demand stops and the correct reaction to vehicles with official duties like police, fire department or ambulance vehicles. In particular, interchanges without a driver present or the usual stop infrastructure at virtual on-demand stops require more passenger guidance by autonomous transport modes.

Keywords: V2X, C2X, Car2x, VITAL, shuttle, autonomous, traffic light controller, 802.11p.

1 INTRODUCTION

The networking of vehicles via V2X [1] interfaces also enables participation in cooperative driving applications. Cooperative behaviour in the sense of individual actions of single vehicles based on jointly collected data has been demonstrated and investigated, for example, in the publicly funded project Transaid [2] and Maven [3].

In the BMVI-funded project "SIRENE" [4], the networking of special forces with intelligent infrastructure was investigated. The aim was to enable optimal routing, considering the current traffic situation. Intelligent traffic lights communicate with the emergency vehicles, priorities the emergency vehicles in case of an emergency and thus enable a green wave for them. The communication took place via 802.11p (V2X).

The networking of vehicles was also investigated in the research project "KoMoD" [5]. At intersections, public transport traffic was prioritized by means of phase shifting or green time extension. For this purpose, information about the position, direction of travel, speed and line and route are transmitted on the vehicle side.

The acceleration of public transport vehicles has been known for a long time [6]. In order for the acceleration of public transport at traffic lights to be successful, additional components are required. An appropriately equipped vehicle and a radio-capable traffic light control unit. In order for the traffic lights to receive the signals and thus give priority to public transport, they must be equipped with radio receivers and an adapted traffic light or signal program. The traffic light systems are controlled by sending data telegrams via analogue radio data Transmission. These are sent to signaling points. These are virtual points on the route that were defined with meter precision in the planning phase. In addition to information about the reporting point, the transmitted "telegrams" also contain the line and course number of the requesting vehicle. The basic principle of a pre-announcement, main announcement and sign-off, as well as reporting points, is to remain in place. The only difference is that communication will now take place with the help of V2X communication and a so-called

WIT Transactions on The Built Environment, Vol 212, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/UMT220011

VDV standard telegram R09.16 telegram [7] in order to allow autonomous public transport to communicate with other road users and to cover other use cases.

The paper should be used to explain this principle in more detail. First, the V2X communication is explained in more detail. A range measurement was then carried out, the results of which can be found in Section 3. In Section 4, the new traffic light control methods are presented and how they are used. Section 5 explains the technology, how the RSU communicates with the OBU on the bus and what data is exchanged. Finally, a test was carried out on a test site in order to have tested the new process before it is used in real traffic. In the last section, the training and the result are explained.

2 V2X COMMUNICATION

The IEEE 802.11p [8] communication standard has been defined together with a special purely software-defined protocol for information exchange between roads vehicles. Therefore, it is called Vehicle2Vehicle (V2V) it can be used to communicate with the infrastructure as well and is then referred to as Vehicle2X (V2X) communication. Wider use in the automotive environment will lead to high market penetration [9] and availability as well as extremely low cost for the technology. Here, messages will be exchanged between vehicles using car-to-car communication (C2C) or via roadside units (RSU) using car-to-infrastructure communication (C2I).

V2X is a WLAN-like standard used in the automotive sector to exchange information between vehicles and/or the infrastructure [10]. This messaging standard is used, for example, in road traffic to immediately warn and support drivers in emergency situations. For this reason, V2X components have been developed and tested for several years. However, this communication standard is not limited to the automotive industry, nor should it have anything to do with the means of transport. The use of V2X communication in road traffic has been evaluated in a number of projects. In principle, it is possible to exchange information across modes of transport.

For the testing and evaluation, use cases in the field of public transport were defined and designed that enable economic operation through V2X application. On the basis of these use cases, it could be shown that on the one hand the use of V2X standard is possible and on the other hand the use of cost-effective standard components from the automotive sector is also target-oriented in public transport.

In order to enable communication between vehicles and infrastructure, which is relevant, e.g. for intelligent assistance systems in vehicles, standards for vehicle-to-infrastructure communication (V2X) have been developed. The European Telecommunications Standards Institute (ETSI) has developed a set of standards for this purpose.

V2X messages are exchanged between receivers via the extended WLAN standard IEEE 802.11p in the 5 GHz frequency range. Research is also being conducted on V2X communication via mobile networks. Studies show that although LTE achieves higher latency than communication via 802.11p, it has better scalability and enables communication over long distances or worldwide.

For data exchange in the WLAN standard IEEE 802.11p, the ETSI ITS G5 standards [11] specify the required network architecture. The ETSI ITS G5 was developed to describe the architecture and network mechanisms for V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure, e.g. roadside units) communication.

Four standardized messages were used in the research project, which are briefly explained below: Cooperative Awareness Messages (CAM) messages are status information about vehicle position, driving speed, driving direction, vehicle status The CAM messages are sent out once per second. The Decentralized Environmental Notification Message (DENM) is a message about location and traffic data as well as traffic situations and danger spots. The Signal Phase and Timing Extended Message (SPATEM) is real-time information transmitted by control units. The MAPEM contains information about the topology of a road or intersection that is required for automated vehicles – in principle the map of the traffic light system.

3 RANGE MEASUREMENT

Since we have no information about the local conditions in the different test environments, we first need to measure how far the V2X messages can be sent and received. This is done using a range measurement, which has already been tested many times and is therefore accurate enough to provide an initial estimate of the correct transmission of V2X messages. The range measurement was performed with a Cohda Wireless MK5 [12] RSU – as base station, as well as with a Cohda Wireless MK5 OBU in the vehicle – with the latest available firmware version. The antennas used are originally supplied by Cohda. The recording was done with the help of Cohda's own field measurement tool, which is included as standard on every Cohda wireless box. The evaluation of the generated files was done with a DLR tool specially developed for range measurement. The modulation used was a 12QPSK, which calculated the range with different packet lengths of 100, 400, 800, 1500 bytes. The location of the measurement was Berliner Straße in Berlin Reinickendorf, compare with Fig. 1.

The RSU has the following coordinates: 52.584175, 13.288600.

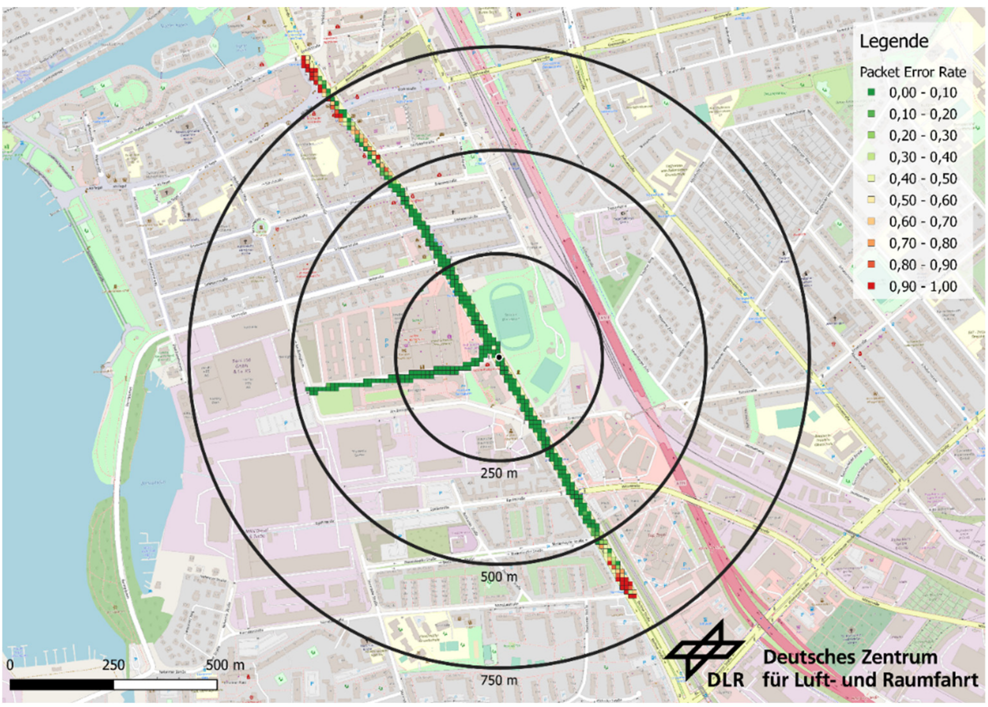

Figure 1: Range measurement with PER.

The evaluation is based on the packet error rate (PER) [13]. This error rate refers to the data packets that were not received. Non-received data packets can be recognized by means of the message ID. During the evaluation, several messages in a previously defined measuring section are combined to form a measuring point. The PER of these measuring points are averaged and designated as PER. Three categories were defined to subdivide the PER at the measuring points. A PER of less than 40% is considered the best possible result and is marked with a green dot on the overview map. A PER between 40% and 60% is still considered an acceptable result, as increasing packet losses can already be expected here. The reception of messages can also no longer be accepted with multiple transmissions. In the overview map, these measurement points are marked with a yellow dot.

The last category is a PER of more than 60%. Here, the reception of a message can almost no longer be accepted. Occasionally, reception may still be possible, but the message may be so faulty that it can no longer be used. These measuring points are marked with a red dot in the overview map.

The subsequent evaluation of the results shows that in urban areas a range of about 500m is achieved due to the coverage by buildings and trees. Since 50 km/h is often the speed limit in German city centre, we calculate with this value for better comprehensibility. The speed limit is given in km/h and is divided by 3.6, resulting in m/s. That is 13.88889m/s.

Formula for uniform motion:

$$\mathrm{s} = \mathrm{v} \times \mathrm{t},$$

where is “s” the distance in meter (m), “v” is the speed in meter per second (m/s) and “t” is the time in seconds (s).

$$500\ \mathrm{m} = \frac{50\ \mathrm{km}}{\mathrm{h}} \times \mathrm{t},$$

$$\mathrm{t} = \frac{500\ \mathrm{m}}{13.88889\ \mathrm{m/s}},$$

$$\mathrm{t} = 36\ \mathrm{s}.$$

This result corresponds to a communication range of 36 seconds at 50 km/h. On smaller access roads, speeds of only 30 km/h are often permitted, resulting in a time span of 60 seconds that can be used for communication. The speed limit is given in km/h and is divided by 3.6, resulting in m/s. That is 8,33333 m/s.

$$500\ \mathrm{m} = \frac{30\ \mathrm{km}}{\mathrm{h}} \times \mathrm{t},$$

$$\mathrm{t} = \frac{500\ \mathrm{m}}{8{,}333333\ \mathrm{m/s}},$$

$$\mathrm{t} = 60\ \mathrm{s}.$$

If we now assume V2X communication with a transmission frequency of 1 Hz for CAM messages and 10 Hz for DENM messages, this already results in stable communication.

4 VITAL PROCEDURES: TRAFFIC-DEPENDENT INTELLIGENT CONTROL OF TRAFFIC LIGHTS [14]

Intelligent control procedures for traffic light systems (LSA) represent an important element for traffic control. Against this background, two novel traffic signal control methods were developed at the German Aerospace Centre, which consider the central technical innovations in the field of traffic data acquisition and thus contribute to an improved traffic management.

The essential innovation of these procedures lies in the traffic parameters used for control and the infrastructure used for their acquisition. Up to now, traffic lights have not been controlled with variables such as lost time, and the vehicles themselves, with their built-in recording and communication options, have not yet been used as sensors for traffic light control.

The experience from the projects and also from the knowledge about the novel traffic light systems control procedure should enable us to integrate the autonomous buses into road traffic in such a way that they can be accelerated better in urban traffic or be provided with an extended green phase.

5 EMPIRICAL ANALYSIS

The first step was to set up the system using the bus registration. Here, a pre-announcement was carried out first. This signals the approach of the public transport vehicle to the intersection in advance. The circulation for the priority of the direction of travel is prepared in the control unit of the traffic light. Subsequently, the registration at the traffic light systems is executed by the public transport vehicle. This indicates the immediate arrival of the public transport vehicle at the intersection. The priority of the direction of travel of the public transport vehicle is initiated in the traffic light systems. If a pre-announced public transport vehicle is at a stop in the intersection area, the announcement is only made when the door is closed and the vehicle starts. Finally, the de-registration is carried out. Here, the control system is informed that the vehicle has passed the intersection. The traffic light systems return to its regular cycle.

In the previous section, the regular procedure of a public transport prioritization was presented. During the research project, however, V2X communication is to be used for the autonomous shuttle buses of the public transport system. Thus, the investigation of a procedure for the integration of V2X-based traffic control information for cooperative applications was aimed at. Here, the decision making has to be placed on V2X messages. For the system, SPATEM/MAPEM messages or CAM/DENM messages were exchanged. The traffic light systems send out the messages with the help of an RSU. These can be received up to 500 m from the intersection, as described in the section above. The public transport vehicle also uses an OBU to send out the V2X messages received from the RSU. A simple illustration of the system is shown in Fig. 2. Here, the control unit is equipped with an RSU to send V2X messages. The public transport vehicle has a C-ITS (Cooperative Intelligent Transport Systems) OBU and sends out Cam or DENM messages, which are received by the RSU at the control unit. Meanwhile, the traffic light system sends out its status and topology information to all road users using the SPATEM and MAPEM.

During the automated navigation, implementation and testing of selected cooperative applications for traffic control using V2X communication, cooperative applications for traffic control using V2X technology were tested as a real-world laboratory test on DLR premises and in the test field [15]. For the tests, corresponding modules were implemented on the test vehicles.

6 SCENARIO TEST AND RESULTS

For the scenario test, an intersection was set up in Berlin. Here, detection hardware and the corresponding control system were implemented in a control unit from the laboratory. Care was taken to ensure that the intersection in the test field was set up exactly like the intersection

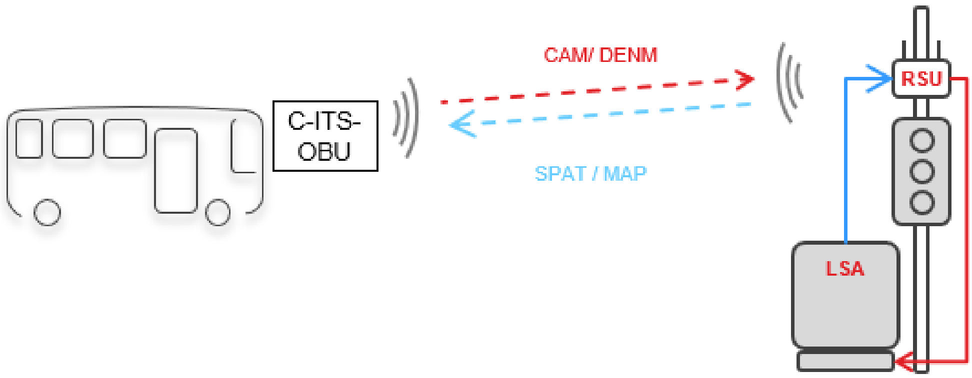

Figure 2: System setup with V2X messages.

in the real world. It has been set up as a four-arm intersection where a main road – in this case Berliner Straße – is crossed by Brunowstraße as shown in Fig. 3. A complete public transport registration was carried out at the control unit as described in the system setup. Subsequently, the sign-off was sent by the test vehicle and the prioritization for the vehicle was cancelled again. The test intersection can be seen in Fig. 3.

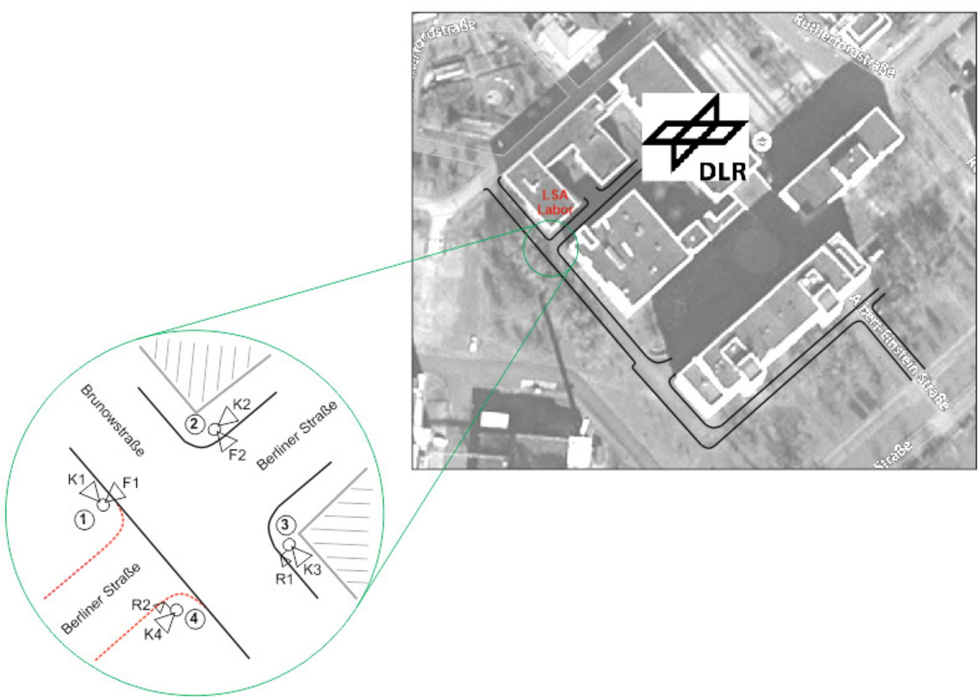

Figure 3: Test intersection on DLR site.

In order to be able to test the detection hardware in the field, it was equipped with detection hardware of the type ThermiCam2 [16] from FLIR at a junction where the range measurement was also carried out. This has an integrated heat sensor and detector for vehicles, vulnerable road users such as cyclists and pedestrians as well as the detection of wrong-way drivers. The ThermiCam2 also works in the dark, as the system only detects the heat emission of road users. Thus, the sensor detects vehicles and vulnerable road users even at night, at long distances and in unfavorable weather conditions. This data is then processed in a simulation and thus feeds back into the VITAL Control system, helping to implement a better traffic flow by changing control procedures. This implementation can be seen in Fig. 4. The C-ITS vehicle communicates with the traffic light systems and the RSU. A long-term test is currently in progress. Currently, only data from April 2022 onwards can be used for analysis. MAPEM and SPATEM messages have also been created for both intersections to allow the autonomous vehicles to communicate with the intersection.

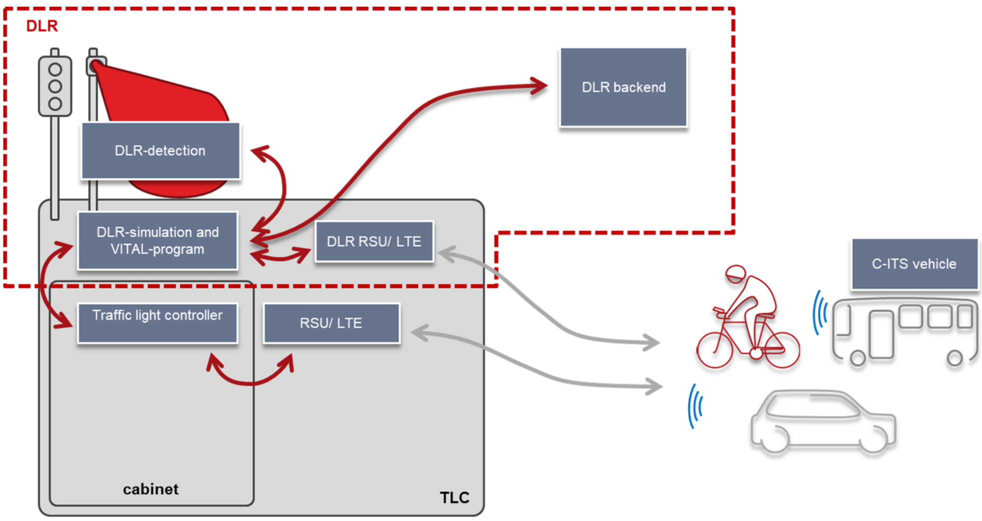

Figure 4: System overview.

7 CONCLUSION

In the context of the Shuttles & Co [17] project, it was shown that V2X communication does not have to be limited exclusively to the automotive sector, but that there are also sufficient fields of action for the public transport sector. During the project, the focus was on the exchange of information between a public transport bus and the infrastructure system in a use case. The research project can also report a further development with regard to the VITAL procedure, in that for the first time the lost times or predicted arrival times at the stop lines of the vehicles will be considered for the control of the traffic light systems. This is possible through the communication of the intelligent traffic lights with the cars using the built-in detection and V2X communication technology. With the lost-time-based and the cooperative method, two novel approaches to traffic light systems control have been developed that are fundamentally based on information from vehicle-infrastructure communication (C2I). These have so far been tested and evaluated in extensive simulation studies. Since vehicle-to-infrastructure communication (C2I) between traffic light systems and vehicles is not yet sufficiently available, an interim solution with fixed detectors from the company FLIR had to be created to record the characteristics. The two new traffic light systems methods were then integrated into the existing control systems in such a way that their structure and basic parameters remained unchanged. The loss-time-based method can be completely mapped on a standardized traffic light system control unit independent of the manufacturer, while the cooperative method requires an additional computing unit for the exchange of information with the traffic light systems control unit. With the future use of vehicle infrastructure communication (C2I), control procedures could change fundamentally, even far below the equipment rates of full equipment. Since the VITAL procedures have so far only used information from private vehicles for control purposes, there is a need for further research and development in the integration of public transport, special purpose vehicles, pedestrians and cyclists. In principle, these can already be integrated into the procedures, as they do not distinguish from which road user, for example, information on position, speed or lost time status originates. However, a separate treatment would be advantageous here – especially for special purpose vehicles with rights of way, not to mention the challenges in detecting vulnerable road users such as pedestrians and cyclists.

The special feature is also that the already existing fixed infrastructure can continue to be used for this purpose and supplemented by V2X technology or completely replaced in the future. This saves infrastructure costs and enables a short-term market introduction.

The V2X communication solution presented here is also subject to a security-critical aspect in terms of availability, integrity and confidentiality. For security reasons, options for the use of public key infrastructures were discussed and proposed.

The V2X communication protocols already defined by ETSI are currently based on communication between road vehicles and between road vehicles and infrastructure.

The offer can be extended by possible on-demand stops and correct response to Vehicles with official duties like police, fire department or ambulance vehicles.

In particular, interchanges without a driver present or the usual stop infrastructure at virtual on-demand stops require more passenger guidance by autonomous transport modes.

ACKNOWLEDGEMENTS

The work presented here was funded by the Federal Ministry of Digital Affairs and Transport (BMDV) in the AVF Projects program. The results presented here were produced as part of the project “Shuttles & Co – Autonomous Shuttles & Co in the digital test field of urban traffic” (FKZ 01MM19011-C).

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