Implementation and Testing of V2X-Applications for Near Future Urban Traffic in Berlin

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***Abstract*— With the emergence of automated vehicles in future urban traffic, the aim is to achieve enhanced connectivity and cooperation among these vehicles themselves, as well as with traffic control systems, to ensure increased traffic safety, even within a mixed operational system. In the project KIS'M, an "AI-based system for connected mobility" is being tested, aimed at addressing the challenges of autonomous, driverless, and on-demand operations in dynamically expanding service areas. In this paper we focus on the importance of interaction between vehicles and cooperative infrastructure for automated and connected driving. In particular, the implementation and testing of cooperative applications in the KIS'M project in Berlin, Germany is presented. The expansion of cooperative infrastructure and related approval processes are addressed, along with the use of cellular communication for increased road safety. Various use cases and recommendations for future expansion are also presented. The paper emphasizes the need for standardization and technical feasibility to achieve widespread use and improve traffic flow.**

Keywords—Cooperative Intelligent Transportation Systems, C-ITS, V2X, Road safety, Cloud-LDM

I. INTRODUCTION

The success of automated and connected driving hinges upon the seamless interaction between C-ITS-enabled (Cooperative Intelligent Transport Systems and Services) vehicles and cooperative infrastructure. The expansion of such infrastructure, especially outfitting traffic signals with roadside units offering diverse communication interfaces (Cellular-V2X Communication and ITS-G5 Dedicated Short-Range Communication), primarily lies within the purview of municipalities. However, often, these entities lack established processes for this endeavor.

This paper presents the practical implementation and testing of cooperative applications within the test field of the KIS'M project (AI-based System for connected Mobility) in Berlin-Reinickendorf [15]. KIS'M aims at the realization of a demand-driven public transport service with driverless vehicles. Improved connectivity and cooperation of automated vehicles with each other and with traffic control will play a crucial role in achieving higher road safety, even in a mixed system [16]. The selection of use cases is based on the European V2X strategy and the current state of research, both topics are addressed in chapter II. V2X standardization, new rules, and new applications (e.g., Cooperative Perception Message) required a review of the use cases and technical implementations pursued so far (e.g., in relation to 5G mobile expansion).

Chapter III shows the infrastructure expansion in the test site Berlin, and how approval processes in the administration for the extension of cooperative infrastructure can be designed and established.

One focus of the implementation is based on the expansion of V2X via cellular communication (C-V2X), so that all road users including pedestrians and cyclists can benefit from this information by using smartphone apps, contributing to increasing the road safety of vulnerable road users. For V2X networking via cellular communication, a powerful publish/subscribe architecture is necessary, which must fulfil various requirements. Chapter IV presents a cloud-based local dynamic map (LDM) backend implementation that can provide real-time information to different clients.

Chapter V presents a selection of different use cases implemented in the projects. In particular, the networking of vehicles via Cooperative Perception Messages, a new V2X

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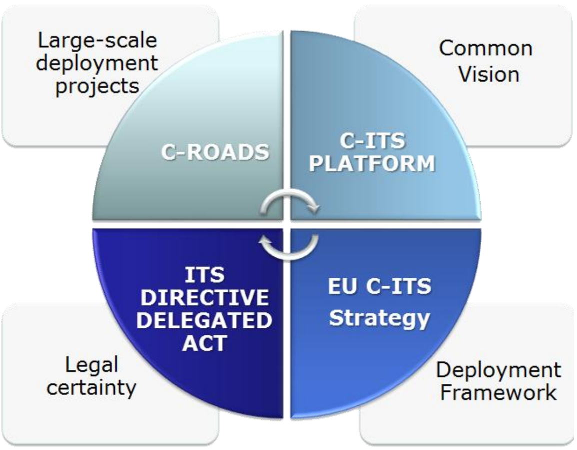

Figure 1: European C-ITS Framework [1]

message that is currently in the ETSI standardization process, and from which further applications, such as the generation of an up-to-date map with cooperative-SLAM approaches, will result. A GLOSA (Green Light Optimal Speed Advisory) service, which can be accessed via a smartphone app, is presented to support all road users. Finally, concepts of V2X-based traffic control for emergency services and public transport are shown, and control procedures based on cooperative V2X / LDM are defined.

In the last chapter VI, recommendations for action are derived so that further expansion can be designed, and applications can be quickly deployed on a broad scale.

II. RELATED WORK/STATE OF THE ART

For the introduction and further development of C-ITS in Europe, it must be ensured that all the different activities follow a common goal, and that the results can be combined into a functioning overall system. This is why the EU has launched the so-called CCAM initiative (Cooperative, Connected and Automated Mobility).

Figure 1 shows the interaction of four key elements for the European CCAM initiative. Part of this joint funding is the C-Roads project [6], which is co-funded by the European Commission. C-Roads is a project for the harmonized equipment of the European road infrastructure with V2X and C-ITS functionalities. The C-ITS Platform was launched in 2014 to bring together stakeholders from all sectors of C-ITS on European roads (member states, road authorities, vehicle manufacturers, suppliers, insurers, etc.) and to develop a common vision for C-ITS in Europe. Their final report [2] was published in 2017. The fourth building block of the CCAM initiative is the creation of legal certainty through a common legal framework for C-ITS. However, the Delegated Act drafted for this purpose in 2019 was rejected by the European Council, so that this legal certainty for C-ITS in Europe is still lacking.

Research is also being conducted with high priority on the mapping of local traffic events. Under the heading of the Local Dynamic Map (LDM) [3], various concepts are still being tested as to how large areas can be mapped, and how the data can be distributed and re-used. Especially when using LDM for traffic control (per se a cooperative procedure), the local specifics and the European dimension must be considered simultaneously. This paper shows the implementation of a cloud LDM that can communicate with different clients.

In several projects – also on a European level – research is being conducted on testing perception and prediction (environment awareness) also using V2X communication via ITS-G5 and mobile radio. In this context, new V2X applications and networking via cellular communication for vulnerable road users are being investigated here.

A thorough analysis of the potential of vehicular communication is presented in [4][5]. It shows various scenarios and stakeholders taking economic constraints into account. A case study is performed on the infrastructure requirements in Berlin.

III. V2X INFRASTRUCTURE IN TEST FIELD BERLIN-REINICKENDORF

The development and realization of V2X in the field should stabilize the traffic flow and further contribute to the implementation of Vision Zero strategy. The necessary expansion of the V2X infrastructure and the testing of automated and connected driving in cooperative infrastructure on public roads is strongly tied to regulations and administrative approval processes. Necessary organizational and technical processes are not yet fully known and established in the municipalities, but partly also on the manufacturer side, and must therefore be coordinated taking into account the advancing standardization. In addition, the initial technical situation and organizational set-up often differ greatly from municipality to municipality.

After an analysis of the existing infrastructure in the test field Berlin-Reinickendorf, necessary additions are initiated, and the approval procedures required in the state of Berlin for the selected V2X use cases are coordinated.

The planned and partly already implemented infrastructure expansion in the Berlin-Reinickendorf test field concerns the supply of traffic signals with a new generation of Roadside Units (RSU), which can communicate via IEEE 802.11p (ITS-G5) as well as via cellular connections (see Figure 2). Altogether there are 26 traffic lights that will be equipped with new hardware and software. The RSU have to fulfil the following requirements to implement the use cases planned in Berlin:

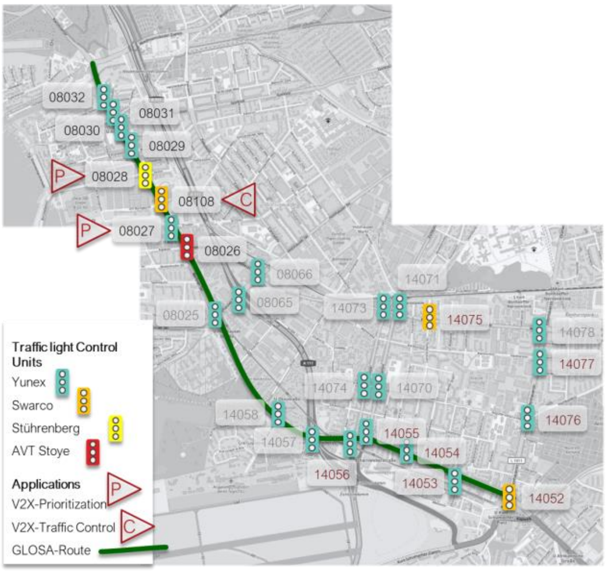

Figure 2: Equipment of traffic lights in the test field

- Sending of SPATEM (Signal Phase and Timing Extended Message) and MAPEM (MAP Extended Message) messages to enable GLOSA-Services (see chapter V.C); SPATEM extended by a forecast specifying the beginning and ending of the next signal phase; MAPEM extended by lanes and signal groups for pedestrians and cyclists.
- Receiving of CAM (Cooperative Awareness Message) messages in order to derive the request of a priority handling by detecting of approaching busses/ vehicles/cyclists.

The testing of V2X priority control is planned at two traffic lights (see Figure 2, P), and traffic control via V2X at another traffic light (see Figure 2, C). The dark green line marks the route where the GLOSA Use Case can be demonstrated.

IV. ARCHITECTURE – CLOUD LDM

When using V2X via cellular communication, a higher number of potential users can be reached, as the information can also be made available independently of the vehicle by using smartphones. The infrastructure, vehicles, and users exchange V2X-messages and data with a backend via cellular communication. The backend hosts the processes für V2X-data-handling, user's applications but also for security issues (certificate handling, updating, etc.). The advantage is that communication is also possible over greater distances (local range or worldwide). A possible disadvantage of this solution is the higher latencies that are to be expected with communication via a backend in contrast to direct communication via ITS-G5. An analysis of the latencies occurring in the Berlin test field will be available in the course of 2024.

The following describes the objective and the requirements that are necessary for the implementation of a globally scalable, geo-based publish/subscribe communication middleware. The realization of the cloud LDM (hereafter referred to as LDM++) is based on standard state-of-the-art software and tools such as Kubernetes, Apache Flink, Apache Kafka, and Terraform. The implemented software was deployed on a target system (Microsoft Azure). By using standards, deployment on other cloud solutions is also supported.

The architecture of the communication middleware is based on the following high-level illustration (see Figure 3).

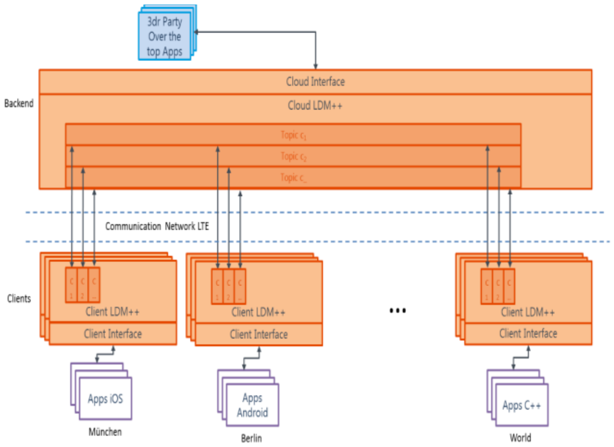

Figure 3: High-level mapping of the publish/subscribe architecture of the LDM++ Cloud

The various locations in the figure represent the fact that any number of clients can be distributed worldwide.

A key point in the solution of a globally scalable geo-based publish/subscribe communication middleware for the transmission and distribution of located data is the fulfilment of the requirements regarding performance and latencies.

Table 1 shows different use case classes and their requirements for maximum end-to-end delay, number of messages per time unit and client, message size (payload) and number of maximum clients.

Table 1: LDM++ Requirements

Use case Class	LDM++ Requirements			
	Delay	No. Of messages	payload	No. Of clients
Hard Real Time	0.1 sec	100 mes. Per sec per cl.	1 kB	20
Soft Real Time	1 sec	20 mes. Per sec per cl.	10 kB	1000
No Real Time	5 min	1 mes per minute per cl.	100 kB	10.000.000

Mobile clients communicate with the middleware via the client interface shown in Figure 3, which is available on the following platforms/programming languages: Android, iOS, Windows, Linux, C++, Java, Swift. The relevance of a message in the middleware is defined for its recipients on the one hand by its location and a relevance radius, and on the other hand the recipient must have subscribed to the topic of the message.

V2X-capable vehicles, which are also equipped with an extensive sensor setup, can transmit information generated by themselves (e.g., warning of an expected red light violation by another vehicle, indication of an approaching emergency vehicle) and information received from others (e.g., SPATEM messages, but also third-party warnings) to the backend. The following example application shows the subscribed topics and the process when warning of a Red-Light Violation (see Figure 4)

A. *Example Use Case Class: Hard Real-Time*

The cyclist has subscribed to the communication channel of the traffic light and receives the information that the green light for the respective direction will continue for another 5 seconds. The cyclist must accelerate in order to use the green phase.

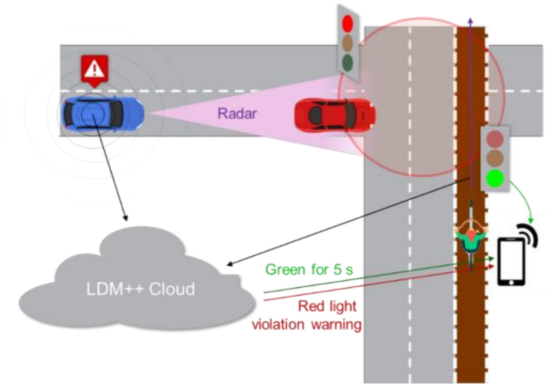

Figure 4: Principle of Red-Light Violation warning

The red car (which is not connected to the LDM++) misses the red light and drives through the intersection. The blue car sees the red car running the red light because it receives the signal information from the traffic light and detects the position of the red car by radar. It sends a warning on the "red light violation" channel for the area marked with the red circle. The cyclist is subscribed to this area and receives the warning.

The next example shows a GLOSA-service received by a tile-based LDM-Implementation. For the geo-referencing the location and the relevance radius are mapped to a discrete „Global Grid System“ in the LDM++ (Client and Backend), which is transparent for the users. The concept of indexing geographic data is based on slippy map tiles, thus multidimensional geographic coordinates are mapped to a one-dimensional tile-index. The global grid completely covers the earth's surface without overlapping each other and it is hierarchically ordered and available in several resolutions.

B. *Example Use Case Class: Soft Real-Time*

Traffic lights constantly send their real-time signals to the cloud LDM, which the clients receive to calculate an optimal speed when approaching the traffic light. Figure 5 shows the route of a vehicle that has subscribed to the signal phase topic on a tile-based LDM and can thus successively adjust the speed on the entire passage.

C. *Example Use Case Class: No Real-Time*

An example application that does not have real-time requirements is a Far Traffic Jam Warning. Vehicle 1 is on a highway near an urban area and shares information about the current local traffic situation (e.g., traffic jam) with a certain radius of relevance which is extended over several map tiles. Many other vehicles can use this information to optimize their routes, even if they are still far away. Thus vehicle 1 sends a warning about the traffic situation in relation to these tiles with a time limit of 30 minutes and the exact relevance radius. Even if vehicle 1 leaves the area and the warning remains active in the cloud for 30 minutes. Up to 10 million vehicle clients can subscribe to the traffic situation topic on all tiles of their route. For each subscription, the server must calculate whether the planned route is affected. All subscribed clients must be informed within 5 minutes.

The performance tests carried out so far have all been successful; for example, the latency for the Hard Real-Time class in the defined scenario was only 29 ms and was thus well below the required maximum time. Further extensive tests with several vehicles in the field are still pending and are to be carried out next year.

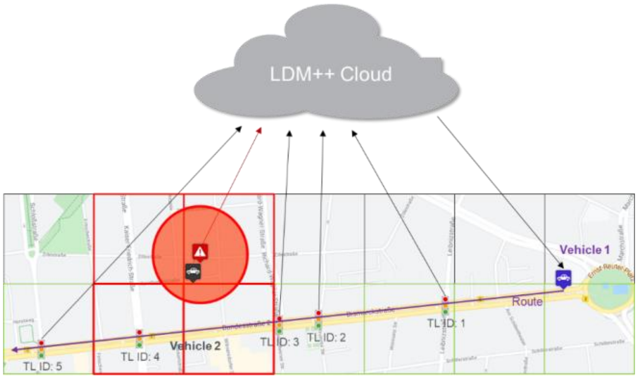

Figure 5: GLOSA Service in a tile-based LDM

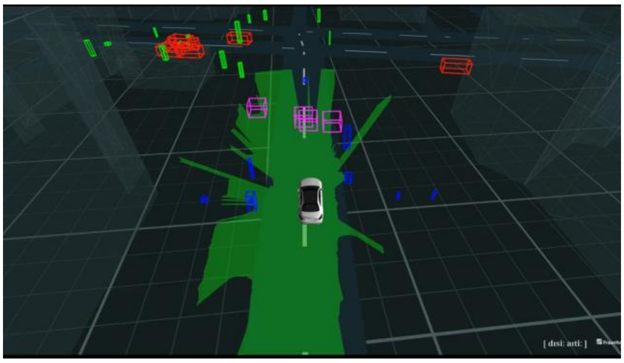

Figure 6: Visualization of Collective Perception

V. V2X-APPLICATIONS

The V2X-applications planned in the KIS’M project were compared with the list of C-ITS services of the Car-to-Car-Communication Consortium [5], and the use cases to be pursued further were defined. In this paper, three different applications are presented that are based on established V2X messages and those that are currently being standardized.

A. *Cooperative Perception Message*

The first use case is based on the Cooperative Perception Message (CPM) [7][8][9] for Cooperative Perception, Object Detection, and Routing, which is currently under standardization at ETSI.

The CPM is designed for collective data exchange between vehicles. Vehicles can share their own sensor data with other road users. This allows them to extend their own environment model with the data of other road users. The message contains information about sensors of the sender and objects detected by the sender. Included is information about the position, orientation, and speed of the sender. The detected objects include their relative position and orientation to the transmitter, the speed, size, and type of the object (e.g., Class:Vehicle, Subclass:Passengercar).

The messages are transmitted periodically, with slow or static objects being transmitted less frequently than fast highly dynamic objects. The objects transmitted in this way are collected in an LDM and can then be inserted into the local LDM of the ego-vehicle, taking into account the position inaccuracy of the transmitter and the uncertainties in the detections of the transmitter. The CPM message is implemented according to the ETSI specification [9], but some compatible changes were made, as the CPM has not yet provided for a precise classification of static objects, which are used e.g., for cooperative localization procedures. Therefore, for the subclass ' OtherSublassType ', frequently occurring static objects were added. Thus, 'poles' was additionally introduced as an object type. However, since the object type is represented as an enum by a number, and the corresponding field allows 255 possible values, of which only two are defined yet in the specification, the message can also be decoded by receivers that do not consider the added types.

To be able to communicate the perception data and maps, the CPM ASN.1 definition [9] is extended as follows (extensions in bold):

- OtherSublassType::= INTEGER {unknown (0), roadSideUnit (1), **pole** (2),**wallSegment** (3), **wallEdge** (4)} (0...255)

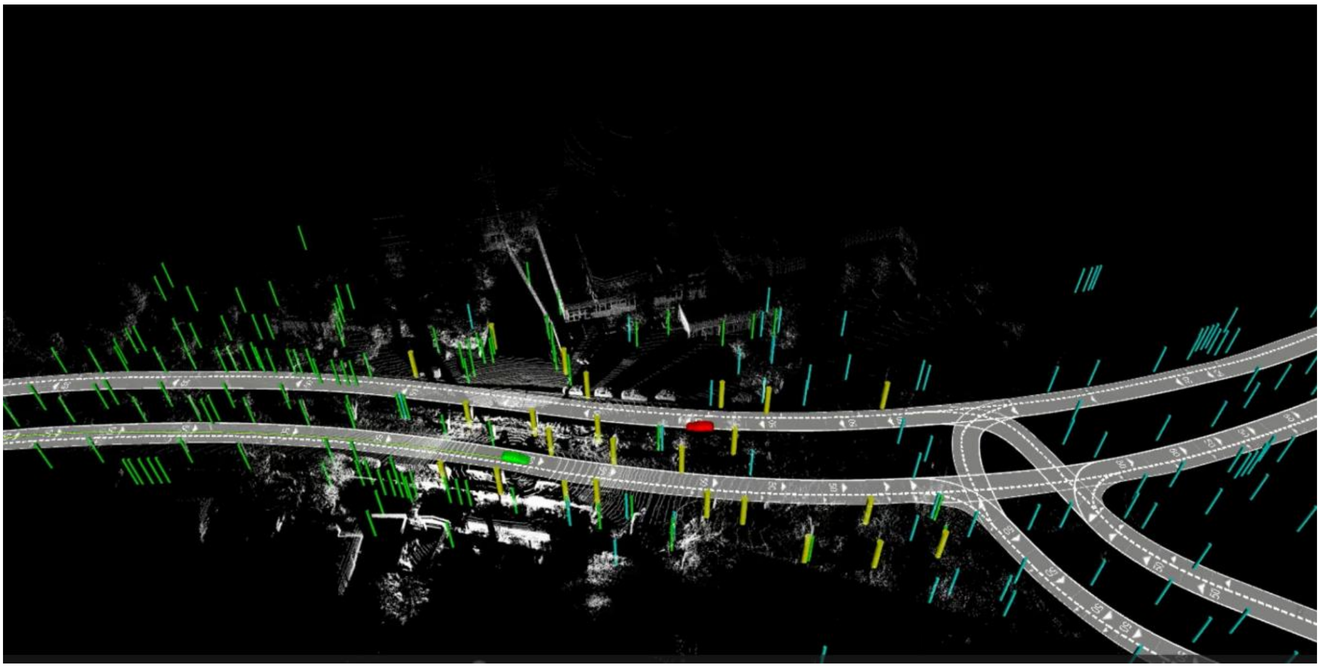

Figure 7: Cooperative SLAM test using two connected vehicles.

The extended CPM was used as a common interface between all test vehicles in the project. The LDM of every test vehicle was upgraded, so that the receiving vehicle could map the received information and take the received objects or road users into account for its own route and trajectory planning. In addition to increasing the own localization accuracy, CPMs were also used to improve the vehicle's environment recognition. For this purpose, a tracking system was developed that fuses the received CPM objects with the local perceptions, making it possible to include objects that are hidden from the own sensors. The channel load was always in a range, in which all CPM messages could be received without loss, so that an adjustment of the transmission rate was not necessary.

A visualization of the LDM with Collective Perception is depicted in Figure 6. It shows objects detected by the sensors of the ego vehicle as well as objects received through CPMs. The purple boxes are other traffic participants, e.g., cars, detected by sensors, while the blue boxes are poles detected by the ego vehicle. Additionally, the red boxes are objects that are not visible by the ego vehicle but have been received through CPMs. The green boxes again are poles that have been detected by other vehicles only. This visualization shows real-world data from a test drive in the test area. For visualization, the PHABMACS [7] simulation software is used.

B. *Cooperative SLAM*

Simultaneous Localization and Mapping (SLAM) is a critical technology in moving robotics. Specifically, laser-based SLAM has gained widespread adoption in applications, such as autonomous driving, due to its superior resistance to environmental interference and higher measurement accuracy than vision-based methods. Cooperative SLAM aims to address the challenge of coordinating a group of connected vehicles to collaboratively construct a consistent global map using all available data while concurrently localizing themselves on the map. The collaboration of multiple vehicles can result in faster and more accurate localization and mapping tasks than those achievable by individual vehicles, which is particularly advantageous in large-scale environments. However, this necessitates the exchange of perception information among vehicles. V2X technology empowers connected vehicles to communicate with other vehicles and intelligent roadside infrastructure in a standardized way, enabling data sharing and collaboration between network nodes. We explore the potential of organizing multiple connected vehicles to work together to achieve cooperative localization and mapping [17].

Sparse pole-like structures are extracted from LiDAR point clouds as perceptual features due to their ease of detection, suitability for encoding and transmission in V2X networks, and stability as landmarks for vehicle localization.

We conducted real-world experiments with two connected vehicles. Figure 8 shows that green and red vehicles start from different areas, perceive the environment, and construct their local maps (green and cyan, respectively). When they encounter each other, they encode their local maps into CPM and exchange them through the V2X network. Since the sensor ranges partially overlap when encountering, there are shared map features in the local maps of the two vehicles. By matching these shared features (shown in yellow in Figure 7), local maps from two vehicles are merged to generate a global map.

The V2X-based cooperative SLAM system enables connected vehicles equipped with standard communication equipment to participate in environmental exploration missions and collaboratively expand and maintain high-definition maps of urban areas.

C. *Traffic Light Assistance for all (GLOSA)*

The application for the use of V2X technologies for all (especially for cyclists) is based on the implementation and integration of a GLOSA [11] service in a smartphone app, shown in Figure 8. The app provides the information to reach the next green phase ahead of the cyclist and to avoid unnecessary stops and accelerations. For this purpose, e.g.,

Figure 8: Smartphone App for GLOSA

speed recommendations for cyclists to reach the green phase for the respective traffic light are displayed in the app.

Traffic lights equipped with an RSU send their topology as MAPEM message and their current state and its expected end-time as SPATEM message. Due to dynamic circuits, e.g., for public transport priority, the SPATEM is transmitted with 1 Hz, the MAPEM much less frequently.

The following additional features/requirements were considered when implementing a smartphone application providing a GLOSA service:

- Integration of an advanced router working on an OSM map and capable e.g., to work with weighted links or avoid links completely.
- Interoperability: App development with Flutter [14] providing support for Android as well as for iOS platforms.
- Integration of pioneers detecting possible damages or other events affecting the desired route

Since it is not ensured that sufficient computing power is available in the end device for routing, map matching, and speed determination, these functions are executed in the backend. During the implementation, care was taken to ensure that the aspects of data protection and data security are fulfilled.

The speed recommendation can be derived based on a forecast communicated by the traffic light (end of green time) and the geometry of the intersection (lanes, bicycle and pedestrian paths and the corresponding routes across the intersection), one's own location and speed. For the cyclist, the location must be matched with the MAPEM data (how long will it take me to reach the stop line at the junction) and the expected signal times (what signal state awaits me on arrival). Ideally, only the relevant information will be selected based on the planned route and geometry.

However, the SPATEM must be calculated every second based on the information of the actual status and the forecast of the signaling status of all signal groups (phases). The control procedures cannot currently provide long-term forecasts as a rule since they also react to traffic requirements at short notice.

The following research questions arise in this context: Should a uniform procedure be used to generate the forecasts? Or should each manufacturer offer its own solution?

There are various procedures for generating the forecasts [12][13]. One possibility is to change the traffic adaptive method in such a way that reliable forecasts can be made. However, this would reduce the flexibility of the current state of the art in planning. Another possibility is to use statistical methods to calculate the next switchover. Which method can be used also depends on the expectations and requirements for the forecasts, for example, with what reliability the forecasts should be made and is rescheduling planned for the generation of forecast data.

D. Traffic Control with V2X

In order to achieve coordination of the corresponding approval procedures, the use cases of emergency response services prioritization and traffic-dependent traffic control, which had previously been solved with alternative technology, were pursued further by developing and testing corresponding V2X applications. Several intersections were identified as suitable for this, and an in-depth analysis was carried out for four intersections. The control systems were first set up in a laboratory before they will be put to a real test field operation as shown in Figure 9 for the "Berliner Straße / Brunowstraße" junction. In this way, proof of the technically correct functionality of the applications can be provided in a safe and controlled environment.

The selection and design of the V2X use cases was primarily determined by their relevance for traffic control in the test field. Planning of the use case "Priority rights for emergency response services" took into account the emergency routes but will react on individual vehicles of the local police and firefighter brigade stations at Berliner Straße.

For the use case "traffic-dependent traffic control" DLR developed a control procedure based on co-operative V2X / LDM, which of course took into account all traffic at the intersection but also reacts on emergency response services. The LDM generated by the test vehicles is also used for V2X traffic control. They are recorded via the RSU of the research intersection and processed in the control mechanism (VITAL process [18]). The additionally required input data of the traffic at the intersection become part of the LDM as simulated V2X messages in the realization or specification of the LSA-LDM.

Currently the draft traffic engineering documents for the implementation of the use cases at three neighboring intersections are finalized in dialogue with the approving authority.

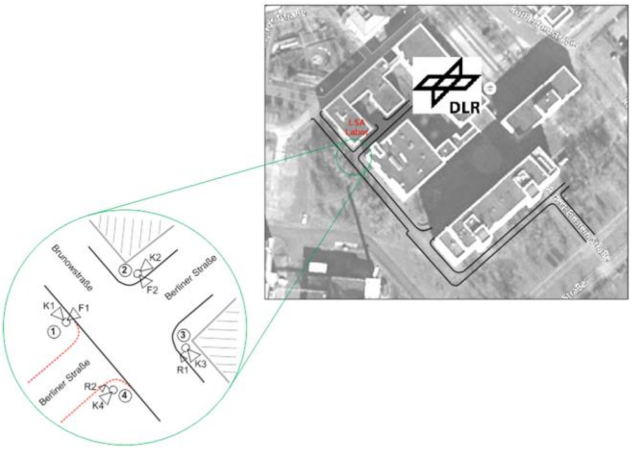

Figure 9: Test implementation of V2X-based Control

VI. CONCLUSION / RECOMMENDATIONS

This paper highlights key advancements in urban mobility, focusing on enhancing safety and efficiency in the context of the KIS'M project [15]. Through the exploration of Cloud LDM, Traffic Control, Public Transport Prioritization, Rule-Based Control, and Automotive GLOSA, significant findings and contributions to future connected urban traffic have emerged.

Implementing Cloud LDM proves pivotal in fortifying road safety by efficiently sharing critical traffic data. This sets the stage for improved traffic management strategies, promising safer and more streamlined urban transportation.

The proof of safe technical feasibility of V2X enabled traffic control mechanisms lays the foundation for widespread adoption, fostering optimized traffic management strategies and correlating with increased traffic efficiency. While expecting a modest 5 - 10% increase in traffic safety aligning with improved throughput rates, the emphasis on technology standardization offers substantial benefits, particularly in congested urban corridors, empowering public transport systems and easing traffic congestion. Implementing rule-based controls at urban junctions is a promising method of enhancing traffic flow and efficiency at and between intersections and thus improving overall urban traffic.

Additionally, the feasibility of Automotive GLOSA integration into advanced city assistant systems marks a significant step toward heightened road safety standards and urban mobility advancements. Extending GLOSA functionality post-rollout to encompass cyclists and smartphone applications in busy city corridors underscores an inclusive approach, enhancing road safety measures for all road users. The integration for instance in public transport assistance systems can enhance their strive to provide an encompassing mobility assistant for individual users.

In conclusion, this comprehensive exploration signifies potential transformative strides in urban mobility. Continued innovation and integration of advanced technologies remain crucial in elevating road safety and efficient mobility and traffic management within urban environments.

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