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C-ITS Service “Traffic Signal Priority” via ETSI G5 (CAM and SREM/SSEM)

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Abstract

Cooperative Intelligent Transport Systems (C-ITSs) enable cities to provide completely new types of C-ITS services. This opens up enormous potential and facilitates safe, environmentally friendly and efficient traffic. This paper explains the C-ITS service “Traffic Signal Priority” (TSP) via ETSI-G5 (CAM and SREM/SSEM message) to prioritize public transport in combination with “Green Light Optimal Speed Advisory” (GLOSA) for approaching traffic lights energy-efficiently. Based on the description of TSP systems, the new possibilities via ETSI-G5 communication are examined. The distribution of the intelligence of traffic control in a centralized/decentralized or a hybrid approach is also discussed. The results of the research simulation study show that an intelligent combination of TSP and GLOSA leads to extended benefits for all road users. Finally, details of the initial implementations in the C-ITS Pilot cities Dresden and Hamburg are presented.

Keywords: C-ITS, traffic signal priority, TSP, green light optimal speed advisory, GLOSA, ETSI-G5, BiDiMoVe, centralized TSP, decentralized TSP, C-ROADS Germany – Urban Nodes, CCAM

1 Motivation

Signalized intersections are main components of city road networks and have a decisive influence on the quality of the traffic flow. Therefore, it is desirable to devise optimal signal control strategies with regards to all traffic participants. Including public transport into the considerations has been studied since decades. Wilbur Smith’s publication in 1968 [13] is often referred to as one of the first publications on transit signal priority, e.g. [1, 9]. Since then the technology has been developed and is practically in use [2, 12].

Today’s ambitions are to update communication technologies from analogue standards to digital systems including the possibility of cooperative ITS [11]. This, however, raises the question of handling conflicting requests of different priorities once again [14].

In the future, mobility will change fundamentally due to increasing digitalization and communication. The availability of reliable information via communication between connected vehicles (CV) and infrastructure (V2I) on the one hand and communication between road users (V2V) one the other hand will enable completely new potentials to be developed and deployed in the future. The efficiency of the existing transport systems and infrastructures can thus be increased significantly.

The deployment of Cooperative Intelligent Transportation Systems (C-ITS) services has already been started. So-called Day1.0 services are and will be available in the near future (<5 years). The launch starts with infrastructure services. Afterwards, vehicles will implement different C-ITS application step by step. The Day1.0 services include, for example, the following C-ITS services:

- GLOSA (Green Light Optimal Speed Advisory) predicts the green phases of traffic lights. Vehicles use this information for efficient and comfortable driving by following an optimal speed advisory and avoid stops and emission. The times remaining until the status change are displayed near traffic lights [10].
- TSP (Traffic/Transit Signal Priority) aims to adapt the status of the traffic lights for a prioritized vehicle - e.g. a public transport (PT). Hence, these vehicles can get an earlier green and move quickly in order to shorten travel times and increase road safety.
- PVD (Probe Vehicle Data) gives traffic management centres in future the opportunity to detect and analyse traffic condition, traffic flow and incidence by receiving the status messages sent by the vehicles via ETSI G5 and V2I communication (CAM - Cooperative Awareness Message).

In addition to the Day1.0 services, there are the Day1.5 services. These are services that are currently being researched and developed, but will be available on the market in 5-10 years. VRU (Vulnerable Road User) is one of these services. VRU are defined as non-motorized road users such as pedestrians and cyclists as well as motorcyclists. The C-ITS service VRU detects and records potential or actual critical or dangerous situations. Based on this, a warning is sent to road users based on the detected and classified event.

This is only a brief summary of the first C-ITS services and is far from complete. Nevertheless, the possibilities become clear: Both for the individual potentials for each C-ITS service, as well as for the even greater benefits by combining different services in an intelligent and smart approach.

2 C-ITS Service TSP

2.1 TSP: Status Quo

The C-ITS Service TSP has already been briefly described above. Transit signal priority is not a new topic in itself. For several decades, for example, public transport has been given priority in many cities in Europe and almost all cities in Germany. In Germany, for example, there has been a standard for the transmission of prioritization messages to the traffic light controller since the 1980s.

In order to respond optimally to PT requests, a traffic signal controller needs correct and up-to-date information on the current traffic situation, i.e., possibly all traffic participants including their locations and current movements. Frequently used PT vehicle positioning techniques are odometer, infrared and inductive beacons as well as Global Navigation Satellite Systems (GNSS, such as GPS and GLONASS) [12]. Standard detection systems for general vehicle detection are inductive loops, video cameras, and radar. For vulnerable road users push-buttons are applied [6]. With conventional detection and communication techniques, detection and movement forecasts are often inaccurate, outdated or even impossible to collect. Inaccurate forecasts lead in turn to waste of green times and thus unnecessary negative effects on conflicting traffic streams [5].

Those negative side-effects can develop further when it comes to conflicting TSP requests. If multiple requests have to be incorporated into a current signalling strategy, the overall TSP goal to reduce schedule deviation and enhance reliability of the PT service has to be traded off against the minimization problem to minimize the average person delay of all priority requests [14]. Beyond that, transport policy issues (e.g. favouring certain modes of transport) as well as social necessities of emergency response (thus prioritizing emergency vehicles) have to be included in signalling strategies [12].

2.2 TSP: New Chances

However, new technologies and features on the vehicle and infrastructure side offer significantly more opportunities to prioritize means of transport at signalled intersections efficiently and in an optimized manner in the overall transport context. Due to the precise location of the vehicles, differentiated authorization concepts and thus a mapping of the driving trajectories within the entire approach of the traffic lights, control decisions can be made much more precisely than before. The different types of traffic and their level of prioritization can also be fully taken into account in the decision-making process.

Emerging CV technologies, e.g., diagnostic sensors in/at all traffic participants and infrastructure as well as their near real-time communication, allow for more accurate data, being comprehensive in space and time. Together with more detailed information about all participants on travel speeds, positions, arrival rates, acceleration rates, queue lengths, numbers of passengers as well as about signal phases and timing (SPaT) of the traffic lights, PT and emergency vehicle prioritization may become more efficient in terms of travel time reductions, safety and environmental impact [5, 11].

Major current projects in Germany with V2X-based PT prioritization are KoMoD / KoMoDnext in Düsseldorf[1], VERONIKA in Kassel[2], SIRENE in Braunschweig/Magdeburg[3] BiDiMoVe in Hamburg and C-ROADS Germany - Urban Nodes in Kassel and Dresden. This paper describes experiences of the latter two projects.

2.3 TSP: Central and decentralized approach

There centralized and decentralized approaches concerning the prioritization in public transport. Hence, there are two ways of organizing the intelligence of the system. A distinction is made here between decentralized approaches to prioritize directly on the signal controller of the traffic lights vs. central approaches to prioritization as part of a traffic management system. It is clear that the PT vehicle (e.g. a bus) must be included in the system architecture. Also, the part of this integration in the overall system of the public transport vehicle mainly depends on the centralized or decentralized approach type.

2.3.1 Centralized TSP

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[1] https://www.bmvi.de/SharedDocs/DE/Artikel/DG/AVF-projekte/komod.html, accessed Feb. 2021.

[2] https://www.bmvi.de/SharedDocs/DE/Artikel/DG/AVF-projekte/veronika.html, accessed Feb. 2021.

[3] https://www.bmvi.de/SharedDocs/DE/Artikel/DG/mfund-projekte/beschleunigung-von-sicherheits-einsaetzen-sirene.html, accessed Feb. 2021.

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In this variant of TSP system, a central system organizes and manages priority requests coming from many different vehicles to the back end system. The centralized Traffic Signal Priority Request works best if a large number of vehicles and intersections need to be organized. In addition, access the Traffic Control Centre (TCC) and the Traffic Management System (TMS) is required as well as means to communicate between all participants. Several realisations are possible:

1. The ‘priority request system’ may be located on the transit vehicle if that vehicle is equipped with a Global Navigation Satellite System and can communicate directly with the Traffic Management System.
2. The priority request system may also be located at the Traffic Management System. The decision to request priority can be determined based on the requests coming from all vehicles in the field.
3. A third scenario is possible in this type of system wherein the ‘priority request system’ is based at the Traffic Management System and happens in real-time as vehicles approach intersections. In this type of system, the amount of communication between vehicles, signals, and the two types of management centres can become complex.

2.3.2 Decentralized TSP

The key difference between the two system types is that in the decentralized TSP systems, all priority decisions are made at the intersection level, rather than at a central location. Distributed systems take less management, but the decision to grant priority can be less differentiated than if a centralized location were managing it. Because of that, decentralized TSP systems are the more popular and, at the moment, widespread approach.

In this type of system, the transit vehicle itself makes a request for priority each time it approaches an intersection. This method requires less communication between traffic and transit management centres than centralized TSP. Still, problems can occur in this system, e.g., the accuracy of information might not be always up to date, because of unexpected changes of the route (road works or traffic accidents) or timetable adjustments because of stopping point cutover.

2.4 TSP over ETSI-G5: Message type: CAM and SREM/SSEM

The approaches of prioritization can also be differentiated by the message types, which is used for prioritization. The first interim solution is to integrate the trigger points into the public transport container of the CAM message, which offers a specific field for R09 telegrams. Finally, the standardized messages SREM and SSEM should be used to prioritize the different traffic modes.

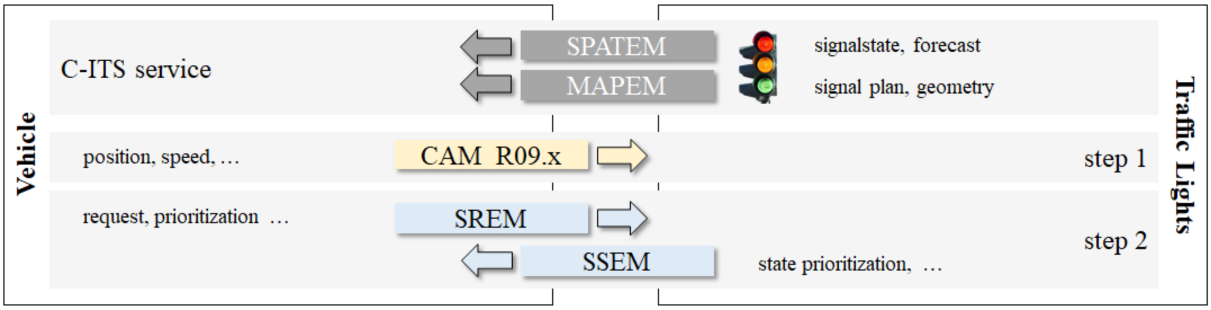

Figure 1: Prioritization via CAM and SREM/SSEM

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Ideally, the C-ITS service TSP should be implemented in steps. This enables the successive installation of the infrastructure and vehicle hardware on the one hand (step 1) and the public transport-specific and traffic light-specific software on the other (step 2).

- Step 1: Interim solution with the use of Cooperative Awareness Messages (CAM) to implement the hardware expansion. This concerns the installation of the RSUs and OBUs, as well as the adaptations of the interfaces between the OBU and on-board computer and between the traffic light controller and the RSU.
- Step 2: Target system using Signal Request and Signal Status Messages (SREM/SSEM) including all necessary software adjustments.

The first step can also be skipped or take place in parallel with the second step.

3 TSP/GLOSA Simulation Study

In the previous sections, we mainly concentrated on the TSP service, but as mentioned above several other services, e.g., GLOSA, are to be deployed as well. The parallel application of several services leads to a global optimisation problem for all traffic participants, e.g., several PT vehicles coming from diverse directions, individual motorised and non-motorised participants as well as emergency vehicles.

In the following it is examined how the services GLOSA – as a possible way to speed up individual traffic participants – and TSP interact using a simulation study. For comparison, the study uses the same network and demand as [7]. The prior study only examined the usage of GLOSA for a certain percentage of the V2X-enabled vehicles. Now, also the usage of TSP is considered. The scenario describes a peak hour scenario (6 – 8 a.m.) on a corridor located in C-ITS pilot city Dresden, near the airport. Over 16,000 individual vehicle trips are simulated using Simulation of Urban Mobility (SUMO) [8]. Four bus lines operate completely or in part on the corridor. These are the lines 478 and 81 in the west as well as line 77 in the east. Line 80 uses the full length of the corridor. During the simulated time frame, 45 bus trips are carried out by those lines in total.. An overview of the corridor, the different lines, and their respective routes is shown in Figure 2.

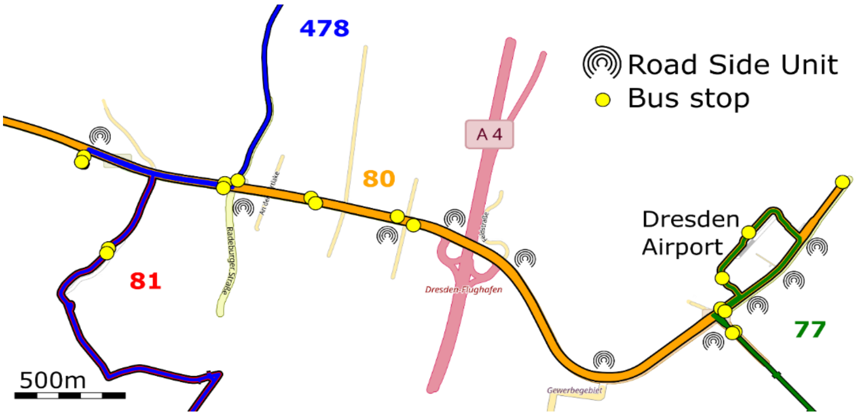
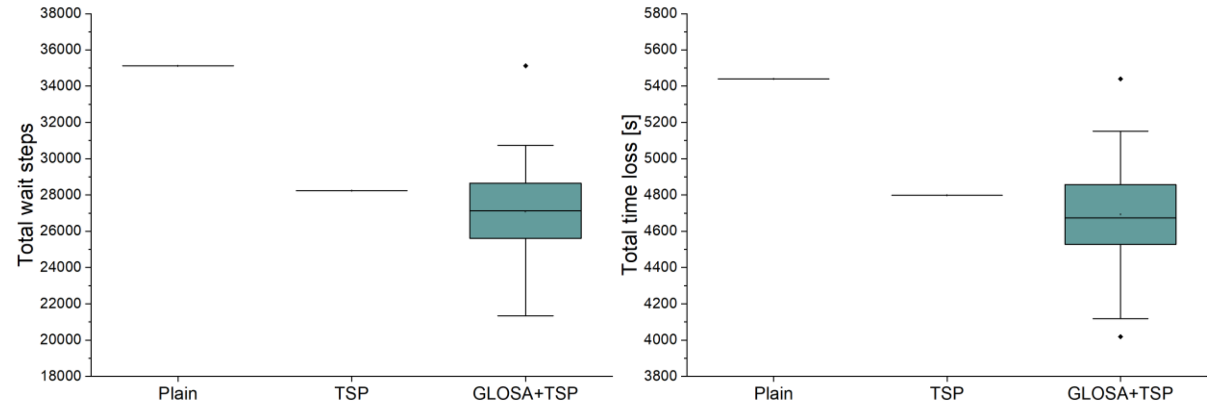


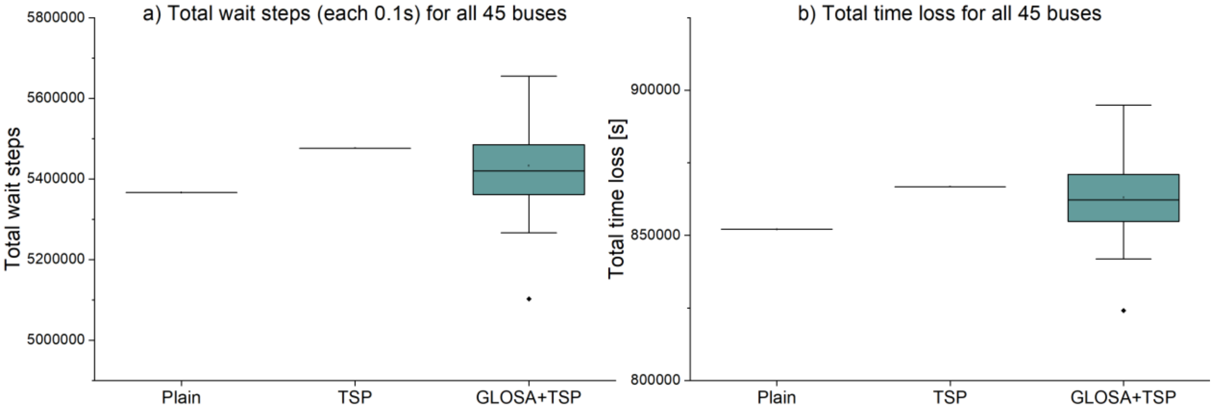
Figure 2: V2X-corridor in the north of the city of Dresden, Germany, used in the simulation study.

TSP in the given case is implemented by recalling the green phase for the relation used by the public transport at the earliest time possible whenever necessary. Figure 3 shows simulation results for wait steps, i.e., number of time steps the buses/vehicles were at stand-still, and time loss. As expected, the usage of TSP significantly reduces the number of wait steps as well as time loss for public transport, whereas it increases the same measures when looking at all traffic participants. What is more interesting and may appear counter-intuitive, using GLOSA (for other vehicles in the network, not for the buses) improves the performance measures for buses even more for most of the time during simulation, where the reduction in wait steps and time loss is significant on the 0.05 level. At the same time, GLOSA also helps to mitigate at least some of the detrimental effects of TSP for the overall traffic, where again the reduction in wait steps and time loss is significant at the 0.05 level. One reason for the observed behaviour could be that vehicles following GLOSA reduce tailback at the intersection. Especially when considering bus stops located before intersections, this allows a faster disembarkation process for the buses as they are not blocked by the aforementioned tail back.



a) Total wait steps (each 0.1s) for all 45 buses

b) Total time loss for all 45 buses



c) Total wait steps (each 0.1s) for all 16,503 vehicles

d) Total time loss for all 16,503 vehicles

Figure 3: Performance measures for the TSP implementation. Plain refers to the case where neither TSP nor GLOSA is employed.

4 C-ITS Services in Pilots

4.1 C-ROADS Germany – Urban Nodes

Since 2019, the harmonization and deployment of C-ITS in urban areas has started in over 43 European cities. As part of the C-Roads platform, the C-Roads Germany - Urban Nodes project will contribute to the implementation and operation of three different urban nodes in Hamburg, Hessen/Kassel and

Dresden. The project supports the large-scale use of C-ITS in urban areas, which offer an adaptation model for the introduction of C-ITS services in Germany in accordance with EU regulations and standards as well as in accordance with the recommendations of the C-Roads platform. Expected benefits include reducing accidents and travel times in urban areas.

4.2 Pilot Dresden

As part of C-Roads Germany - Urban Nodes, various C-ITS pilot services are being implemented in Dresden. The test corridors of the C-ITS pilot in Dresden run over heavily used urban roads, including main roads with connecting functions and access roads. Within the corridors, traffic lights are gradually being equipped for vehicle-infrastructure communication (V2I). The pilot is coordinated by the Fraunhofer IVI. Fraunhofer IVI employees are actively involved in the standardization committees of ETSI. ETSI standards are implemented, tested and further developed in close cooperation with industrial partners. The focus of the pilot is the development of Day 1 services and a Day 1.5 service. These are based on the following C-ITS services: probe vehicle data (PVD), green light optimal speed advisory (GLOSA), traffic signal priority request (TSP), emergency vehicle approaching (EVA), vulnerable road user protection (VRU).

A step-by-step implementation of the TSP service will be carried out in Dresden. In step 1, the activation points R09, which are already in use today, are implemented in the PublicTransport container of the CAM message. The advantage is that no adaptation of the traffic signal control programs are necessary. Only the hardware components (RSU) have to be installed or updated. Furthermore, no adaptation of the interface between traffic light and traffic signal control center and no adaptation of the public transport planning tools and analysis tool are necessary. Step 2, i.e, using SREM / SSEM messages, will be realized at later point. The advantages of continuous registration of public transport prioritization, including response and the continuous travel time forecast within the ETA (estimated time of arrival) object, are undisputed. Due to the higher effort of step 2 compared to step 1, a gradual transition will be done. With regard to step 1, the hardware is installed or updated (radio technology). The other specifics of the local public transport prioritization remain. With regard to step 2, the level of public transport prioritization is upgraded, which leads to a significant improvement in the quality of the prioritization. However, this has an impact on the methods used and, in addition to the necessary hardware changes, which are also necessary for step 1, leads to further adjustments to the software.

The C-ITS pilot Dresden uses ETSI ITS G5 as communication technology. Therefore, analyses of communications ranges for a productive RSU, installed at Comenius-Platz, were carried out as shown in Figure 3. Depending on the approach, maximum communication range is between 265m to 360m. The corresponding receive power is between -95 dbm to -54 dbm. Test vehicle was a BMW i3 with roof mounted antenna. These communications ranges fulfill the requirements of TSP in this corridor in an initial approach.

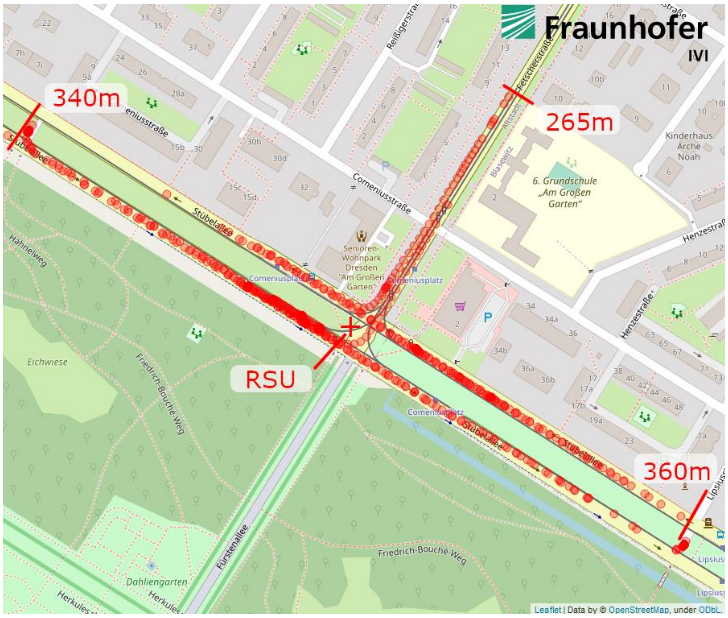


Figure 3: ETSI-G5 communication range in Dresden

4.3 Pilot Hamburg

Hamburg has joined forces to become a pioneer in meeting today’s mobility challenges. With its ITS strategy [4], the Free and Hanseatic City of Hamburg aims to tackle traffic management while focussing on a sophisticated digitalization strategy. Therefore, Hamburg started many different ITS projects like the projects TAVF (Test track for automated and connected driving in Hamburg[4]) and ROKS (Rollout Cooperative Systems Hamburg). The research and development project BiDiMoVe (bidirectional, multimodal, networking) is part of the Hamburg ITS strategy. Its objective is to equip buses and traffic lights with V2X to increase the safety and efficiency of the traffic flow along the bus line M26, which also matters in terms of reducing pollution. To secure communication between the C-ITS components, a public key infrastructure (PKI) with new processes for certificate and its rights management will be specified and implemented. To guarantee the transferability of the V2X services, the new Open Communication Interface for Road Traffic Control Systems OCIT-O V3.0 and OCIT-C V2.0 will be used, which is the infrastructure backbone of the national ITS framework architecture. The pilot is coordinated by the Free and Hanseatic City of Hamburg, represented by the Department of Economic Affairs, Transport and Innovation and the Authority for roads, bridges and waters. Hamburger Hochbahn AG and Hamburg Verkehrsanlagen GmbH are strong partners of the project, who are also the authors of this article. The main goals are:

- Implementation of the EU PKI and an architecture for a “Hamburg PKI”,
- Usage of the new OCIT interfaces, in order to ensure the V2X services transferability,
- Central, dynamic and needs-based prioritization and operation by using standardized messages,
- Integration of a public transport traffic management system to realize the central TSP,
- Display of driving recommendations and control information like GLOSA,
- Testing a V2X-based incident warning system for buses at intersections with VRUs.

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[4] https://tavf.hamburg/en, accessed Feb. 2021.

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In this pilot, TSP is implemented with SREM and SSEM. The vehicle OBU continuously sends SREM everywhere as a request for prioritization at the next traffic lights. The SREM contains the following information, collected over interfaces from the bus, e.g. its ITCS on-board computer:
Position and travel speed, vehicle number, transit status (e.g. door open or parking), route, line and direction, transit occupancy (number of passengers), vehicle sub role or bus product type (express bus, metro bus or city bus), transit schedule: accuracy/delay, battery status, next and following stop, etc..
Sent from the OBU via ITS-G5, the SREM is received by the RSU and forwarded over new OCIT interfaces to the new BiDiMoVe Public Transport Traffic Management System (TMS), where the data is evaluated. By using information about the occupancy, sub role and schedule accuracy of the bus, the TMS calculates the prioritization level for each bus. The detailed information about all participants as well as vehicle type and role, travel speeds, positions, etc. ensures efficient and optimized control decisions for traffic light controlling. This can also contribute to the stabilisation and optimisation of the traffic and at the same time, lead to a reduction of pollution.

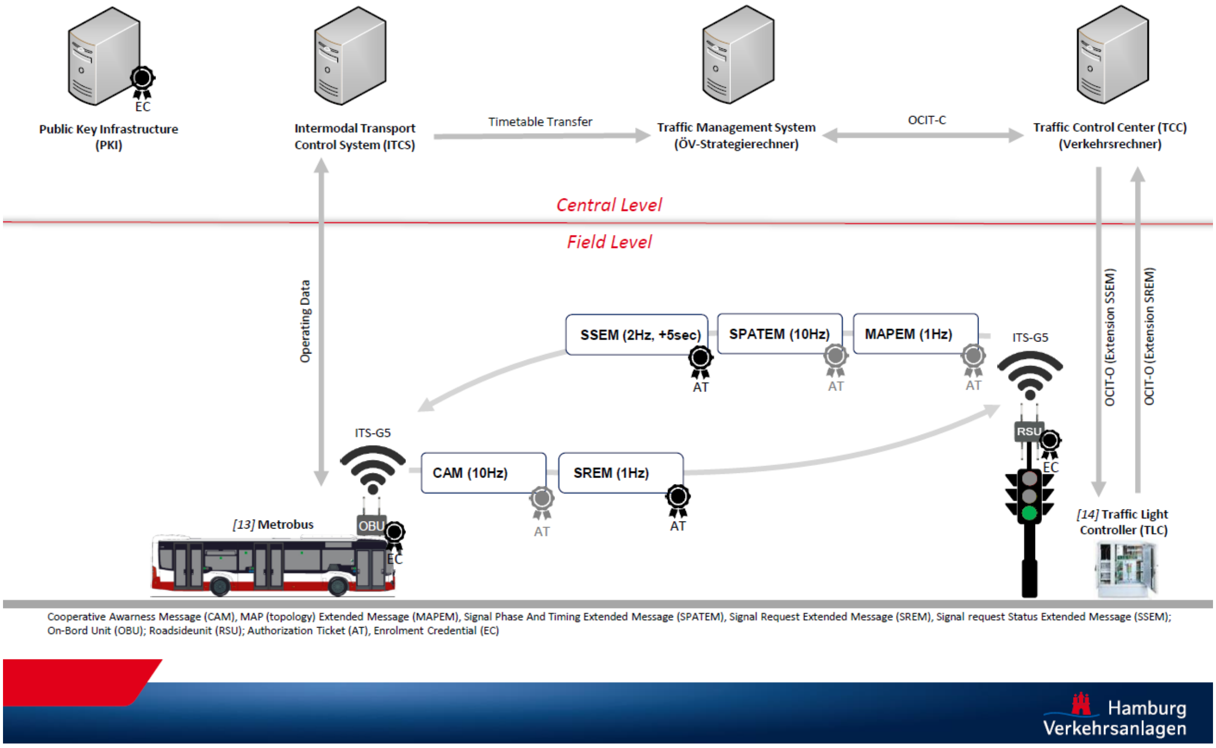

Figure 4: BiDiMoVe central based system architecture and data flows

The TMS needs the public transport timetable for routing each vehicle across an intersection and determining its associated signal group, which will then be included in the SSEM. Thereby it is possible to ensure TSP during detours, which is one big advantage of this centralized management system in contrast to others. For Municipal Transport Services,the central based organized system will also offer new possibilities for its quality management, which becomes more and more important.
The vehicles then receive the answer in the format of an SSEM including prioritization status, traffic

signal status and others from the TMS in return. This allows driving recommendations and GLOSA to be displayed in vehicles.

With this centralized system, the pilot project BiDiMoVe aims to put Hamburg in a pioneering role among German cities in the field of bus priority enhancement at traffic lights.

For a precise prioritization at the next traffic light, the request message must be received as early as possible from the system. Therefore, it is important that the radio ranges are correspondingly large. In a high frequency radio technology, like ITS-G5, these ranges strongly depend on the positions of the antennas.

In order to determine the best position for the ITS-G5 antenna on buses, test drives were carried out by NXP and HOCHBAHN as part of the research project BiDiMoVe. For this purpose, a multiband antenna (Cohda Wireless SMW-303) was mounted at different positions in and on top of the bus while the same test was carried out each time. The signals were processed by a Cohda MK5 OBU, which received SPATEM and MAPEM from traffic lights belonging to the test track TAVF. The optimized positions of RSUs at intersections were defined by HHVA.

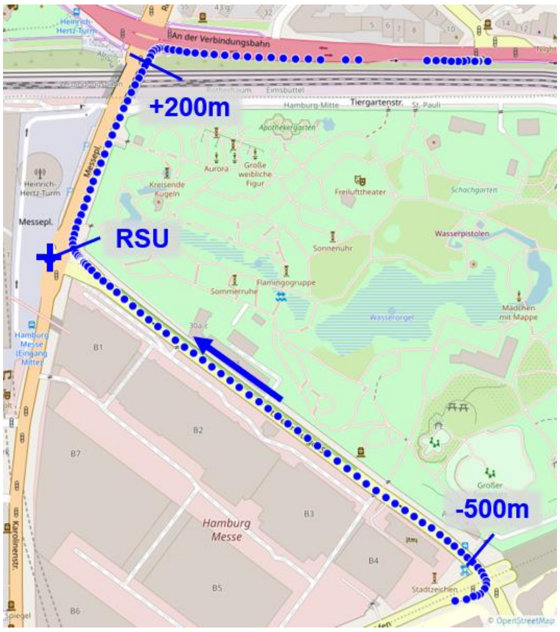

Figure 5: ETSI-G5 communication coverage at the TAVF test track in Hamburg.

As expected, the best position of the antenna was on the bus roof. The performance could be increased by a metal plate under the antenna (counterpoise). The driving tests have been performed at the TAVF test area in Hamburg in subsequent driving loops. The coverage in this urban test area was over 600m at line-of-sight propagation and about 250m in bad conditions with complete shading by buildings. Looking at the coverage overlaying all received massages from RSUs over the test track, the antenna and its position is adequate for the requirements. All approaches to an intersection equipped with RSUs are covered well to realize C-ITS Services. HHVA equips all additional ITS-components in the stationary infrastructure and is also responsible for the continuous operation of the system.

5 Outlook

This paper focused on optimising public transport by using TSP with the different message types (CAM or SREM/SSEM) and the different variants of control (centralized/decentralized or hybrid) and gives important results of research studies, analysis and pilot deployment activities in Dresden and Hamburg. In order to choose the best fitting TSP, it is absolutely worthwhile to undergo a cost-benefit analysis of both the centralized and the decentralized approach. For a possible guideline of a systematic development of such a cost-benefit analysis follow the generic process steps of every traffic signal priority request: request identification, request direction, request time, request priority, status request.

In addition to the content, which is necessary to exchange for the implementation of a TSP in a city, several hardware component on different levels are involved: OBUs, RSUs and traffic management centre. Depending on the implemented TSP variant (centralized/decentralized or hybrid), the allocation of hardware on the different component levels varies. Independent of the TSP variant, all the process steps must be allocated, but on different component levels. For example, in a decentralized approach only the public transport vehicle and the traffic light controller are involved. Nonetheless, it might be efficient to involve a back end system in the infrastructure.

Regardless of what the final decision is for the TSP approach, an important aspect is that the usage of the communication protocol is independent of the respective TSP implementation, i.e., CAM with R09 container as well as SREM/SSEM could be used in either case. This allows for a gradual update of the TSP services taking into account the local specifics.

The results shown in this study focused on the prioritization of public transport. However, when searching for a global optimum, incorporating all traffic participants, additional issues arise. When using SREMs, 16 different types of requester roles have already been defined, including public transport, several types of emergency vehicles or dangerous goods [3]. Consequences of such a classification have yet to be defined in order to apply it to real-world scenarios, such as the value of a delay for the different types of traffic participants. Competing interaction of participants of different as well as the same priority types have to be weighted against each other in real-time in terms of traffic, political, and urban planning objectives. Further research is needed here.

6 Acknowledgement

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