Prioritization of an automated shuttle for V2X public transport at a signalized intersection – a real-life demonstration

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SHORT SUMMARY

Public transport prioritization is used at signalized intersections to reduce travel times and increase the attractiveness of public transport. In the future, analog communication technologies for public transport prioritization are soon to be replaced by the promising vehicle-to-everything (V2X) technology. This abstract presents a holistic approach using V2X communication in public transport prioritization for an automated vehicle. In order to take full advantage of the V2X technology, this means to V2X-enable the traffic infrastructure and change the way of communication as well as the traffic light control. The approach was implemented and tested under real-life conditions at the research intersection Tostmannplatz in Braunschweig.

Keywords: Connected and Automated Vehicles (CAVs), public transport prioritization, traffic light control, V2X communication

1. INTRODUCTION

Since the 1980s public transport prioritization has been used to reduce travel times and increase the attractiveness of public transport. Especially signalized intersections in urban areas are often sources of delays and have a huge impact on the efficiency of the overall transport and of public transport. The restructuration of the frequency band for analog radio provides and useable synergy effects regarding adjustments to the V2X technology. The interest for operation of V2X technology in public transport prioritization increase constantly. The guideline "Applicability of V2X for transit signal priority" of the Federal Highway Research Institute (BASt), recommended actions towards using the V2X communication standards IEEE 802.11p for the public transport prioritization at signalized junctions, and also point out the transformation of analog technologies. (Gay et al., 2022)

In current research, there are approaches that preempt regular traffic along with public transport and emergency vehicles by calculating a coordination in a centralized control system (Petrică et al., 2021). Other research tries to evaluate the merits of preemption (Hwang, 2021) or focuses on the importance of accessibility of public transport systems (Liu et al., 2022). National research projects (KoMoD, VERONIKA, SIRENE, BiDiMoVe, Shuttles&Co, C-ROADS Germany – Urban Nodes) focus on V2X prioritization for public transport or emergency vehicles without considering privately owned road vehicles. This paper proposes a V2X solution for a traffic light control which considers public transport prioritization and individual motorized traffic (Concept 1 (chapter 4)). Additionally, a solution was developed to use connected traffic lights in a different manner to enable future-proof concepts for autonomous public transport like virtual bus stops. (Concept 2 (chapter 5))

The outline of the paper is as follows: First, the two features AGLOSA (chapter 2) and V2X software framework (chapter 3) that are necessary for realizing the V2X public transport prioritization approach will described. Afterwards, the holistic approach for the V2X-based public transport prioritization is described via two concepts (figure 1) in chapters 4 and 5, respectively. The approach means to V2X-enable the traffic infrastructure (TI) and change the communication way as well as the traffic light control (TLC). Concept 1 (chapter 4) shows a common public transport prioritization at a signalized intersection, implemented with V2X, to minimize time loss of automated shuttle crossing an intersection. In Concept 2 (chapter 5) a traffic light and its signals are used to protect automated shuttle (SH) while exit a bus stop, implemented with V2X. Hereby improving safety as well as minimizing time loss for the SH. Both concepts will be implemented at the research intersection Tostmannplatz in Braunschweig. Figure 1 show the intersection's geometry.

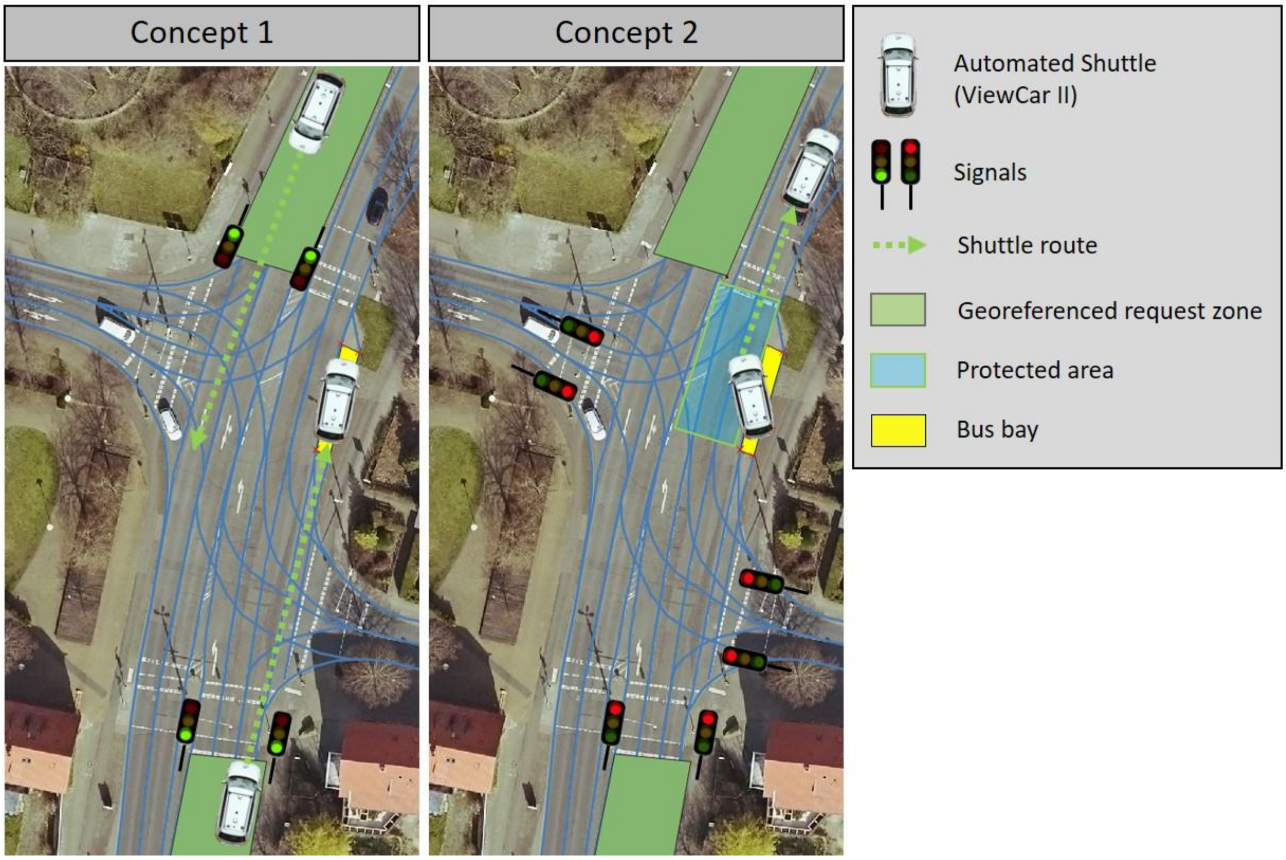
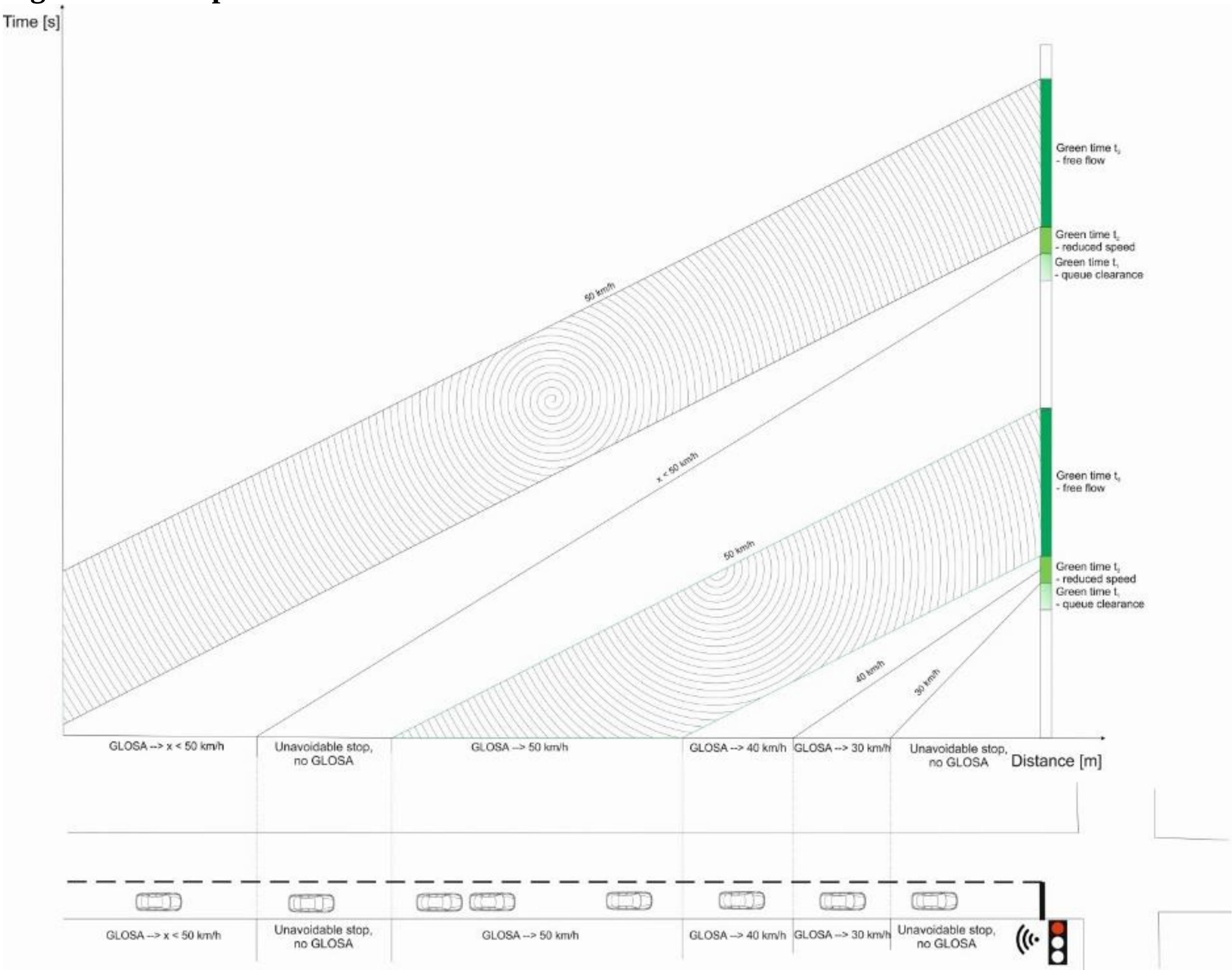


Figure 1: Tostmannplatz intent concept 1 (left), intent concept 2 (right)

2. AGLOSA

In order to allow the prioritization of V2X-enabled vehicles, a TLC algorithm is needed that utilizes connected vehicle data. Conventional TLC schemes such as fixed-time or traffic actuated controls do not provide methods for the reception and processing of V2X data. The method used in this paper is called AGLOSA (adaptive control algorithm with green light optimal speed advisory), an algorithm developed by the DLR and first introduced in (Erdmann, 2013) that incorporates connected vehicle data. The basic approach of AGLOSA is to predict the arrival times of all detected vehicles at the controlled intersection and to plan a phase succession that minimizes a given optimization goal, for example time loss or number of stops. Part of the optimal phase succession can be the provision of GLOSA information for vehicles in order to delay arrivals of vehicles to allow them to pass the intersection without stopping (figure 2). Due to the complexity of the optimization method, AGLOSA cannot be operated directly on the traffic controller and needs to be operated on a separate application unit. To estimate the current state of the real world and thus the positions and time losses of the vehicles, an internal state simulation is run that is described in more detail in chapter 4.

Figure 2: Principle of GLOSA calculation



Within this use case, two methods of detection were employed. Since few vehicles already use V2X, alternate detection methods are required. At Tostmannplatz, magnet field sensors (MS) called Wimag (Typ: Sitraffic Wimag VD) (figure 3) were installed in order to detect vehicles at the intersection's approaches. The big advantage of these sensors compared to induction loops is that they transfer data wirelessly to the traffic controller and thus produce a minimal installation effort.
As an additional data input, infrared cameras (IC) called ThermiCam AI (Type: FLIR ITS ThermiCam AI-325 and FLIR ITS ThermiCam AI-335) (figure 4) for object detection will be installed. These cameras can not only provide presence data of vehicles but also provide a data interface for parameters such as current speed and vehicle dimensions.
Unfortunately, the sensors at Tostmannplatz were not functioning during the field tests and could not be used as data sources. The other detection method is the insertion of an autonomous shuttle through

Signal Request Extended Message (SREM). On message reception, the vehicle position contained in the message is forwarded to the internal state simulation and a vehicle is created and placed accordingly to the coordinate. Whenever a new position is received, the vehicle is moved to this new coordinate. The resulting speed then can be used by AGLOSA to predict the arrival of the vehicle at the traffic light and to calculate the required begin of the green phase.

Figure 3: Sitraffic Wimag VD (Siemens, 2018)

Figure 4: Flir ITS ThermiCam AI (Flir, 2022)

3. V2X SOFTWARE FRAMEWORK

The V2X software framework (figure 5) is a Java application for transceiving (sending and receiving) messages using the GeoNetworking protocol. (Bottazzi et al., 2021) The applications framework hides the complexity required to create, send and receive V2X messages. It provides a user-friendly API that can be adapted to the needs of each use case. For the project, the interface to ROS (Robot Operating System) (ROS, 2022) was used. ROS was suitable because there was no interface for the Python implementation of AGLOSA to the V2X-framework. However, Python programs can be embedded in ROS and thus no new interface had to be created.
For efficient deployment in the field, the V2X transceiver as well as AGLOSA were packed into a Docker container. This allows extensive configuration of the system on a local virtual machine (VM), since only limited online services are available on the system in the field. The finished container was pushed to the Road Side Unit (RSU) via a simple scp upload and was ready out of the box after deployment.

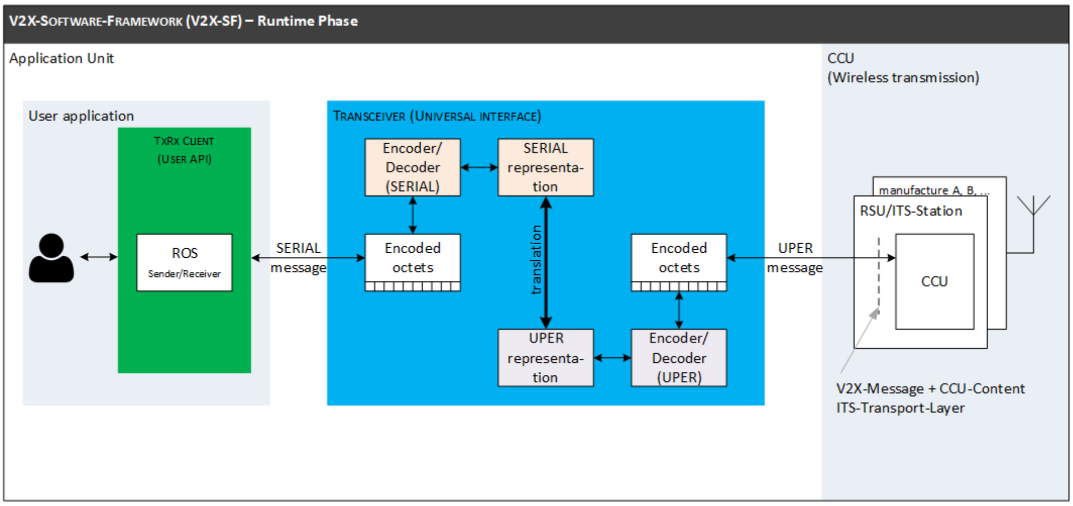


Figure 5: V2X software framework

4. CONCEPT 1

Concept 1 (figure 7) shows a common public transport prioritization at a signalized intersection, implemented with V2X, to minimize time loss of the automated shuttle crossing the intersection:

The route of the shuttle over the intersection is known a priori. Once the automated shuttle approaches the intersection and reaches a georeferenced request zone (figure 1 and 6, green area) it continuously transmits a SREM containing its current position, speed and identity. The RSU receives the SREM and transmits it to an industrial computer (IC). On the IC, the transceiver decodes the SREM and provides the information about the shuttle for the control algorithm AGLOSA.

Figure 6: Tostmannplatz georeferenced request zone

The control algorithm estimates the vehicle arrival times at the intersection with the aid of the microscopic simulation SUMO (SUMO, 2022) and optimizes the phase succession at the traffic light to minimize a given optimization goal (e.g. time loss, number of stops). In the simulation, the entire intersection Tostmannplatz is modelled. All motorized traffic participants are detected through Cooperative Awareness Messages (CAM) 70-100 m upstream the stop lines. For each detection, a simulated vehicle is inserted into the SUMO simulation with its transmitted speed and vehicle type. Through the provision of CAM, the driving behavior of the vehicles can be modelled accurately since their positions and speeds can frequently be updated. If no information should be available for a short period of time, the behavior of single vehicles is estimated by the simulation given the state information of the last message. This state information can be fed into AGLOSA to optimize the phase succession of the traffic light.

The SH provides its state information, i.e. its actual position and speed, via SREM. Compared to all other traffic participants inserted into the simulation, the SH has a very high priority, so that the SH will always be preferred in switch decisions made by AGLOSA. The interface between AGLOSA and the traffic light controller is implemented by sending R09 bus telegrams to the Xfer RSU. The RSU itself generates a V2X message called Signal Phase and Timing Extended Message (SPATEM) from the traffic signal information of the traffic light controller. This message provides information about the current signal states at the signalized intersection Tostmannplatz. From the SPATEM, the SH can directly evaluate whether its prioritization request was granted or not. The standard way of informing about the status of a prioritization request is to send a Signal Request Status Extended Message (SSEM). Since the same information was implicitly contained in the SPATEM, the SSEM was abdicated in this scenario. The SPATEM is broadcasted through the RSU to the automated shuttle. The shuttle’s automation drives according to the information of the traffic light signal state.

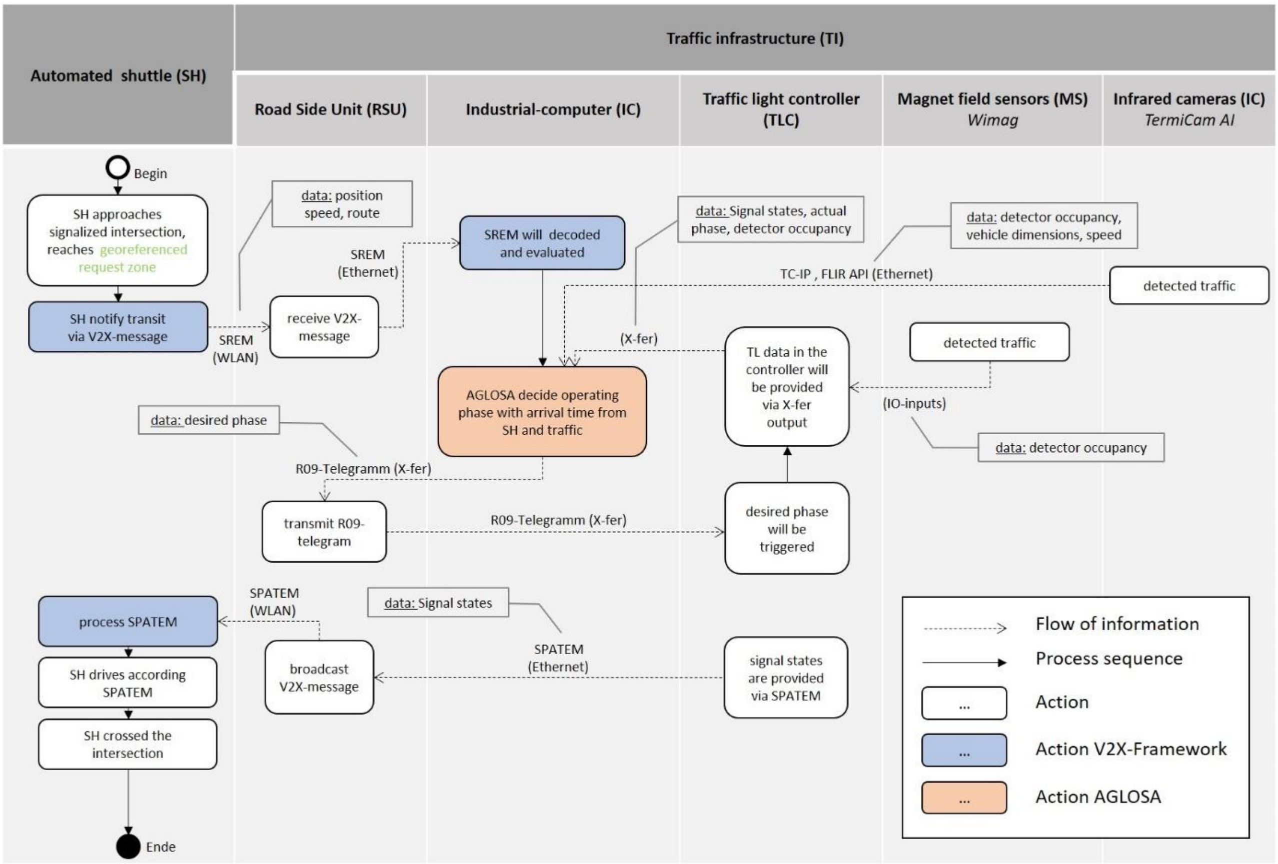


Figure 7: Concept 1

5. CONCEPT 2

In Concept 2 (figure 8), a traffic light and its signals are used to protect the automated shuttle while exiting a bus stop. Concept 2 improves traffic safety as well as it minimizes time loss of the automated shuttle at bus stops.

The process begins after the shuttle has arrived at the intersection and stopped in a bus bay next to the road (figure 1, right frame). As it wants to continue driving, the shuttle sends a SREM in which it provides information about its desired departure from the bus bay. The idea is to protect the SH against other conflicting traffic flows using signals of the traffic light (figure 1, protected area). The shuttle's conflicting traffic flows will get red signals for a short period of time. The automated shuttle now uses its own sensors to check whether the traffic conditions allow for it to drive back onto the road without being protected by signals. If this is possible, the SH exits the bay. If this is not possible, e.g. due to heavy traffic, the SH waits until it receives a SPATEM that indicates the signal states are switched to the protected phase. When there is no more traffic on the lane, the SH drives out of the bay.

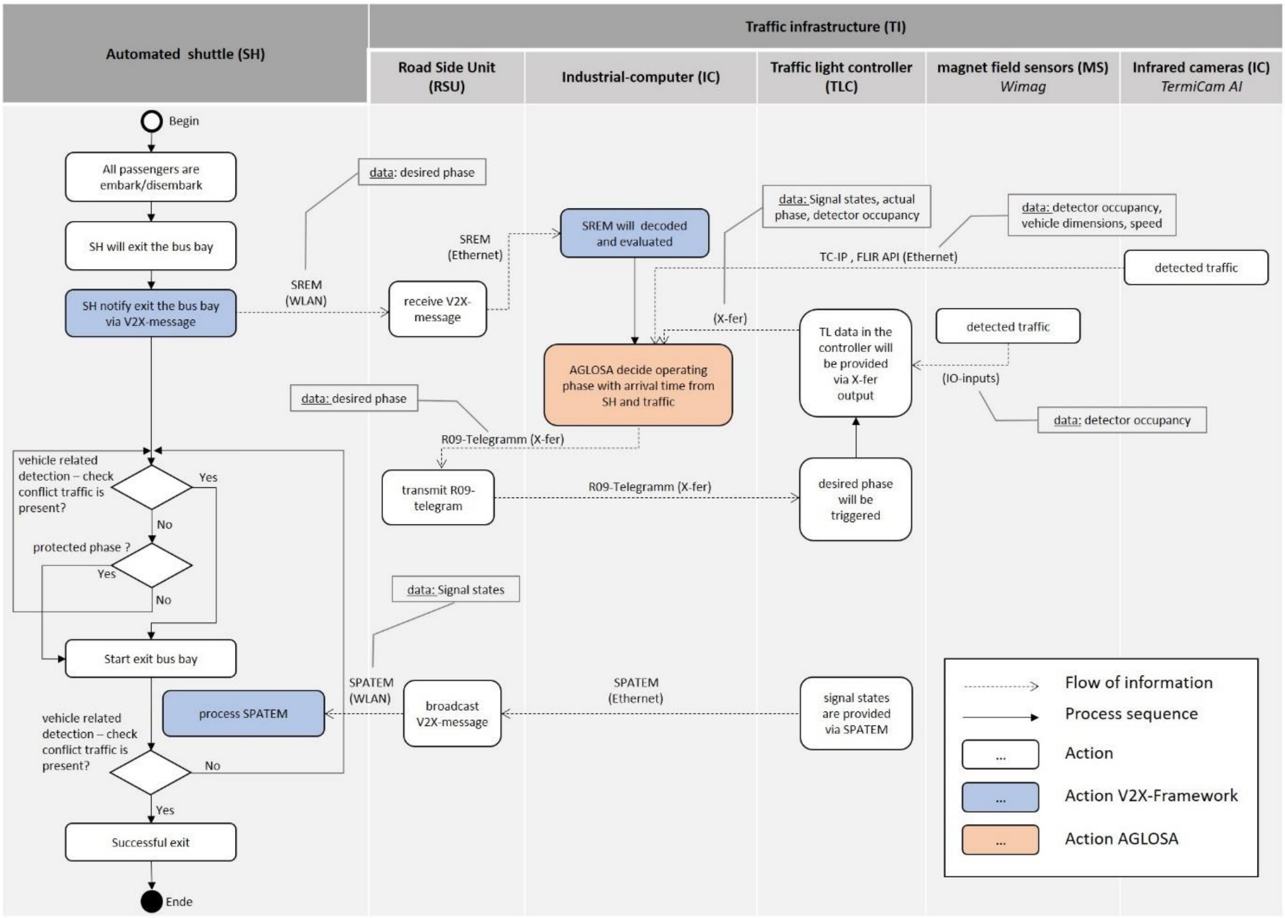


Figure 8: Concept 2

6. CONCLUSIONS

Both concepts were tested at the research intersection Tostmannplatz in Braunschweig. All necessary infrastructure components were already installed, apart from the IC. Unfortunately, AGLOSA could not receive the arrival time of every vehicle at the intersection because the detection of non-connected vehicles was not functional. However, the system architecture proposed in this paper was implemented completely. In tests the research vehicle View Car II (ViewCar II, 2022) of the DLR is used as the automated shuttle. First tests show that all communication channels worked and the automated shuttle could trigger the desired phase in the traffic light control. In the end of the year 2022 the ICs will be installed at the intersection Tostmannplatz. Accordingly, the concepts will be tested with the whole potential of AGLOSA. The implementation of concept 2 determined that the recent standard of SREM only consider a request of green for an inbound and outbound lane. To allow protection of the bus route against other conflict traffic flows, an extension of the SREM standard for requesting a red signalized lane could be interesting in future.

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