A transmission protocol for fully automated valet parking using DSRC

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***Abstract*—Some of the most advanced functions in automated and autonomous vehicles are in the parking domain, since it provides structured environments and slow speeds. Unfortunately, most parking garages also deny GNSS reception, prompting the vehicle to rely on dead reckoning or simple path-finding algorithms. To this regard, we have developed an infrastructure-based positioning system using cameras. In this paper, we present a novel approach on how to utilize dedicated short-range communication (often referred to as "Car-2-X communication" (C2X)) to transmit external positioning to vehicles with low latency. A session-based distributed state machine protocol is used to ensure synchronicity between vehicle and infrastructure. We conducted an evaluation of transmission ranges for typical underground environments and show the feasibility of external positioning for autonomous driving.**

I. INTRODUCTION

Recently, automotive research and development has seen a huge boost in the field of automation from long established vehicle manufacturers such as Daimler, Ford or BMW as well new players such as Tesla, Local Motors or IT companies like Google. This leads to a promise of fully automated vehicles, covering all driving tasks in any given situation (often falsely referred to as "autonomous"). Unfortunately, this scenario still seems far off, especially for difficult driving situations as in urban traffic or under harsh weather conditions [1].

One key area, where the highest level of automation is possible is in parking functions. Thus, already highly automated parking functions are available with current vehicles as in Tesla's *summon* function or with Mercedes' *remote parking pilot*. In further iterations, a fully automated valet parking function, in which the driverless car navigates and parks in a garage on its own, is the logical next step. The actual vehicle control and collision avoidance is comparably easy in this scenario thanks to low speeds. However, the task of self-localization in the indoor parking environments, relative to a map in global coordinates, is much more difficult as most (underground) garages block GNSS reception upon entering. The task of localization is therefore relegated to vehicle-internal sensors like wheel odometry, steering angle indication and yaw rate sensors. Furthermore, vehicles could utilize cameras, radar or lidar to calculate ego motion from sensory perception. All of these methods provide a *relative* position only, and thus will aggregate localization errors over time. Once this error exceeds acceptable thresholds for automated driving, the vehicle has to stop and the valet function will fail.

One solution to this issue is to provide an *external* position from infrastructure-based sensors. Since these can be placed at fixed known positions inside the garage, an absolute position of detected vehicles can be calculated. As we show in [2], such a framework introduces new challenges – primarily the tracking of vehicles over multiple sensors and the matching problem, where n detected vehicles have to be matched with m communicating vehicles, while both sets can intersect in any given way. We provided a solution to detection, tracking and matching in the eValet framework, by detecting vehicles in camera images, spatio-temporal tracking and association to the communication endpoints [3].

To be able to use the externally detected localization information inside the vehicle, a communication channel needs to be established. Several communication methods are feasible to transmit position information back to the vehicle – cellular communication and consumer WiFi are the most prominent. Unfortunately, cellular communication is prone to reception and latency issues, unless a base station is deployed inside the indoor environment. Consumer WiFi with IEEE 802.11b/g/n is a possibility [2], but suffers from range and reliability and long hand-over times in infrastructure mode. In recent years another communication standard was introduced specifically for automotive communication with IEEE 802.11p [4]. In contrast to consumer WiFi this standard provides greater range, lower latency and ad-hoc communication capabilities, making it ideally suited to our task. Current standards SAE J2735 [5] and ETSI ITS G5 [6][7] do not foresee the valet parking function and thus need to be amended.

This paper is further structured as follows: In the second chapter we provide an overview of comparable approaches (external positioning) and past work in the eValet project. We follow up with a proposal for standard messages suitable for external positioning in general (e.g. in tunnels or garages) and valet parking in particular. In chapter four we detail our evaluation conducted in a real-life garage environment using Dedicated Short Range Communication (DSRC) and provide an insight into scaling for bigger garages. We conclude in chapter five with a summary and outlook.

II. RELATED WORK

A. DSRC communication

Cooperative functions have been a huge research topic in past years after introduction of IEEE 802.11p [4] and the corresponding American standard SAE J2735 [5] and the European ETSI ITS G5. In Europe, the DRIVE C2X field-operational trial [8] conducted testing on several national test-sites spanning between 20 and 200 vehicles. The focus was in driver-information to enhance safety and traffic efficiency. Functions were split between vehicle-to-vehicle based as with EEBL (Electronic Emergency Brake-Light) or TJAW (Traffic-Jam Ahead Warning) and vehicle-to-infrastructure as with GLOSA (Green-Light Optimized Speed Advisory). Concurrently, the US field-test Safety-Pilot has been conducted with up to 2000 communicating vehicles. Focus was set on safety-related functions, mostly in the field of vehicle-to-vehicle as with EEBL or IMA (Intersection Movement Assist) [9].

Taking up from these driver-information systems, research has started to investigate a combination of cooperative automated vehicles to enhance ADAS and automated driving functions in projects such as TEAM [10]. We have presented an overview of these novel functions in [11].

B. Autonomous valet parking

Several demonstrations of autonomous (self-sufficient) valet parking functions have been shown in recent years. Groh et al. propose to utilize a laser scanner (LiDAR) to detect garage walls and localize by finding appropriate similarities in a map [12]. Alternatively, Bojarski et al. plan to utilize a camera-based neural network with “end to end” learning for path planning in parking garages, although the task of identifying appropriate parking spots is not further specified [13].

In contrast, Ibisch et al. utilize infrastructure-based sensors, namely LiDAR, to detect and locate vehicles similar to the eValet approach [14]. Altinger et al. further iterate on this approach and propose to utilize IEEE 802.11p communication for transmission of localization information [15]. Unfortunately, no specification on utilized messages is given. A comparable approach was presented by Saito in a showcase for Honda, in which multiple overlapping infrastructure cameras detect automated vehicles and transmit low-latency position data for parking and coordination between vehicles [16].

A model car testbed for automated valet parking with a infrastructure backend that uses C2X technology is shown in [17]. Here the server backend takes care of mission information, such as finding a charging place for the electronic model cars. For localization a line sensor and an RFID scanner are used as sensor within the vehicle. However it is not shown how these sensors could scale in a real-world vehicle.

In [18] the authors present an automated outdoor parking system. Similar to our approach the parking lot occupation is observed with cameras and the information is sent to the vehicles via C2X. The system is only suitable for outdoor parkings as it relies on the vehicle’s own positioning with GPS and Inertial Measurement Units (IMU).

III. TRANSMISSION PROTOCOL

Parking in an indoor parking garage is a tedious activity for most car drivers. It usually includes several steps that are uncomfortable or time consuming for the driver. At the entrance gate of the garage a ticket has to be pulled from a machine. After that the driver needs to navigate through often narrow lanes in order to find a free parking lot. Before returning to the vehicle or at the exit gate the ticket is used to calculate the balance of the parking process. In many cases coins are required to pay the balance.

With the advance of C2X many of the before mentioned activities can be assisted or replaced by communication means. The eValet system [2] allows for guidance of vehicles to an automatically assigned parking lot. Vehicle positions as well as free parking lots are detected by an external camera detection system. A tracking system [3] ensures that the vehicles are captured from the entrance of the parking garage to the parking lot and again from the parking lot to the exit gate. The system is able to support automated vehicles, so that the driver can leave the car at the entrance and pick it up from there again. Nevertheless conventional cars benefit from the system in a similar way by assisting the driver to find the parking lot with onboard navigation systems.

Additionally, the booking and payment process in the garage can be fully automated. Registered users of the system can use their credit card or a third party payment service to settle the parking bill. For regular parkers this can for example occurr on a monthly basis. As the vehicle registers with the system and the occupation of parking lots is detected automatically, the parking duration can be determined.

For the communication between the parking infrastructure and the vehicles DSRC over IEEE 802.11p is used. As extension to the communication messages defined by ETSI, i.e. CAM [6] and DENM [7] messages, we propose a set of message types for guided parking with the eValet system. In [19] the Detected Object Message (DOM) has been introduced, which facilitates the transmission of position data of vehicles and other objects detected by the car park infrastructure.

Parking in an indoor garage with the help of C2X is an example of collaborative driving [11], as the vehicle interacts with the infrastructure and vice versa. For instance, the vehicles need to register with the parking infrastructure to initialize a session. In [20] the Collaborative Maneuver Protocol (CMP) has been introduced for session handling. Thereby CMP defines several Collaborative Maneuver Message (CMM) types, namely *Beacon*, *Request*,*Response*, and *Inform*.

In this paper, we propose how CMP can be utilized to integrate automated valet parking into the ETSI ITS G5 environment. We encapsulate the DOM message into the CMM Inform container to leverage CMP functionality such as ITS G5 integration and automated state synchronization between discrete entities in a wireless ad-hoc network environment.

For the garage, a function-specific implementation to the generic CMP framework is utilized. The garage broadcasts periodic Beacon messages, which indicate eValet capabilities

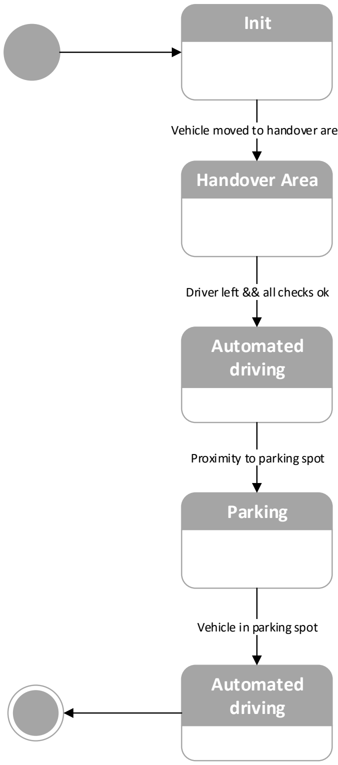

Fig. 1: State chart of the parking scenario

to CMP-enabled vehicles. Once a vehicle enters the garage, it can request a session, which holds coherent information regarding the automated parking function. The session thus serves as a synchronization container for a distributed state machine. The session state (equal to state machine state) can hold these properties.

- Init
- Handover-area
- Automated driving
- Parking
- Parked

Each change to the session state has to be requested with a CMM request message, and is concluded, if all entities (in this function only two entities per session are needed) reply with a positive ACK CMM response message. A synchronization process follows, which uses a variation of the Turquois algorithm as described in [21]. The possible state changes are visualised in Figure 1.

Once the session has been established, it is in the init state. During this state, tracking of the vehicle is established and the capability for automated valet mode is indicated to the driver.

	TS	*vID*	*Width*	*Length*	*Height*	*Type*
Type	long	uint	uint	uint	uint	enum
Unit	msec	-	mm	mm	mm	-

TABLE I: Data fields of message format *VPM*

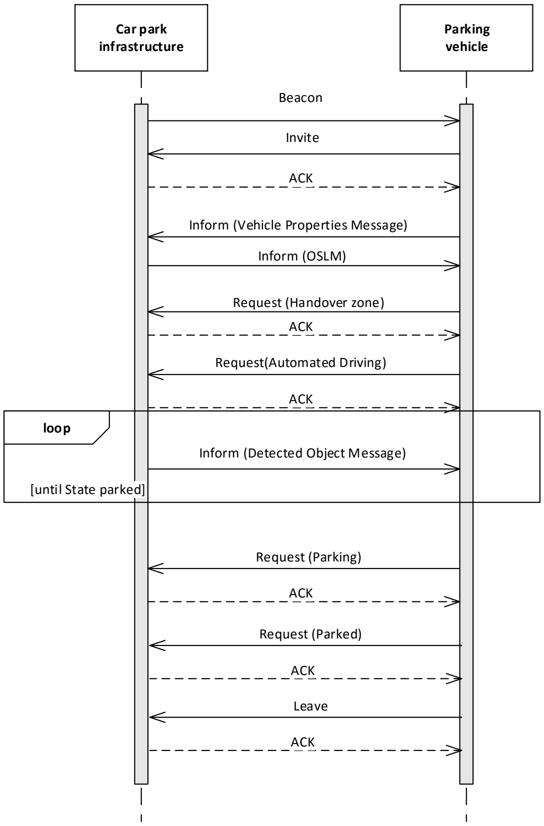

Fig. 2: Message exchange for the parking process

The first message that is sent after the initialization message is an Inform with the Vehicle Properties Message (VPM). The fields of a VPM are shown in Table I. First it contains the Unix epoche timestamp in milliseconds. Consequently it uses the vehicle id that was assigned by the car park system in the initialization in order to indicate which vehicle is sending the message. The message contains the dimensions of the vehicle in millimeters. Furthermore, a vehicle type is included in the message. The vehicle type for instance can be car, motorcycle, van etc. These informations help the car park system to find a parking spot that is appropriate for the vehicle.

Following this, the driver is instructed to guide the vehicle to a handover-area, to stop and leave the vehicle. Once the driver has parked the vehicle, a state change to ”Handover-area” is requested by the vehicle, as described in [20]. In this state, a final check for system capabilities is performed and the parking garage starts to broadcast position information. This broadcast is handled in Inform messages, containing vehicle ID and GeoLocation information. Besides the requesting vehicle, all positions of detected pedestrains and moving vehicles are broadcast to enable collision prevention inside the garage. To this means a Detected Object Message (DOM) is sent periodically in an Inform container. We propose to use 10hz detection frequency.

	TS	*mID*	*vID*	*Type*	*ItemsNumber*	*ItemsList* {*1..**}						
Type	long	uint	uint	enum	uint		*oID*	*NameLength*	*Name*	*Lat*	*Lon*	*Level*
Unit	msec	-	-	-	-	*Type*	uint	uint	string	double	double	int
						unit	-	-	-	degree	degree	-

TABLE II: Data fields of message format *OSLM*

The car park system knows at all times, which parking lots are available and which are occupied. Hence, it can calculate, which parking lots are the closest and can send a list of free parking lots to the vehicle using an Inform message containing the Object Selection List Message (OSLM) in an Inform container.

OSLM is defined so that it can transfer an arbitrary list of geo-referenced objects. The message contains the Unix epoche timestamp, a message identifier, and the identifier of the vehicle to which the message is directed as meta information. Consequently, the type of the list is defined with an enumeration. In our scenario the value of this field is parking lots. For the list of objects, the number of items in the list is defined so that the receiver knows how many list entries need to be processed. The message must contain a least one entry and can contain an arbitrary number of items.

Each entry in the list has an identifier and may have a name. The position of the item is defined by its latitude and longitude values and a level. The level can be a negative number for underground parking garages. The structure of OSLM is shown in Table II.

Once all systems indicate readiness for automated driving, the vehicle request a state-change to ”Automated driving” state and conducts the driving maneuver. In this state, the vehicle conducts local path planning based on received information fused with odometry from wheel odometers and inertial sensors. It furthermore utilizes internal sensors such as Radar, Camera and Lidar for collision prevention with stationary and moving objects. It is important to note, that all internal sensors will always override external information from the DOM, such that no information received from CMP can lead to unsafe conditions in case of misdetections from the infrastructure.

As the target parking spot is reached, a further transition to ”Parking” is requested and the parking maneuver is initiated. As it successfully concludes, the final state change to ”Parked” happens, after which the session is terminated and the garage ceases position broadcasts. The message flow for the process of parking can be seen in Figure 2.

When the user returns to the garage, the car park system handles the billing and the navigation from the parking lot to the garage exit. The process for exiting the car park can be seen in Figure 3. A new session is established between the car park infrastructure and the vehicle with *Invite* message. The garage then requests a state change to ”Automated Driving”, and once the vehicle acknowledges the return path is calculated and the vehicle exits the lot.

Subsequently the vehicle is directed to the next handover zone. As the map data is already stored on the vehicle, the navigation system of the vehicle can find the nearest one and no additional message needs to be sent to the vehicle. However the position of the vehicle, observed by the camera detection system, is sent to the vehicle using DOM in a periodic Inform message until it is recognized in an exit area of the garage.

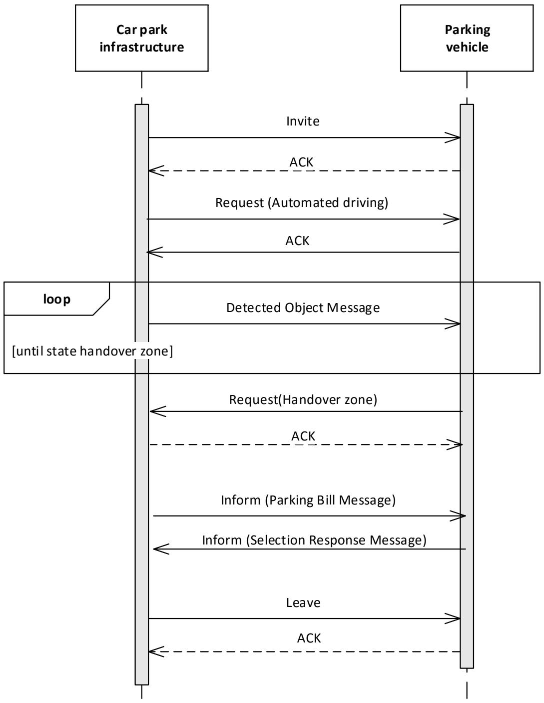

Fig. 3: Message exchange for the exit process

Once the vehicle reaches the handover zone, the driver can unlock the car and enter to resume normal driving. Before the starting, a message with the bill is sent to the driver, the Parking Bill Message (PBM) in an Inform container. The structure of PBM can be seen in Table IV.

The PBM also contains a timestamp and a message identifier to which the receiver can refer in the response. The vehicle identifier is required for addressing the vehicle. The duration field holds the parking time in minutes. Currency and Balance fields contain the amount that is to be paid by the user.

The user can accept or decline the bill in the HMI. To transfer this information, a Selection Response Message (SRM) with one of the two implicit responses *Ok* or *Decline* is sent from the vehicle to the server. If the user declines, the operator of the car park management system can take measures, e.g. review the bill.

The fields of the SRM are shown in Table V. This message also contains the Unix timestamp and the identifier of the

	TS	*vID*	*Lat*	*Lon*	*PosAcc*	*Alt*	*AltAcc*	*Heading*	*HeadAcc*	*Velocity*	*VelAcc*	*Type*
Type	long	uint	double	double	float	float	float	float	float	float	float	enum
Unit	msec	-	deg	deg	m	m	m	deg	deg	$\frac{m}{s}$	$\frac{m}{s}$	-

TABLE III: Data fields of message format *DOM*

	TS	*mID*	*vID*	*Duration*	*Currency*	*Balance*
Type	long	uint	uint	uint	enum	double
Unit	msec	-	-	minutes	-	-

TABLE IV: Data fields of message format *PBM*

	TS	*vID*	*rID*	*Selection*
Type	long	uint	uint	uint
Unit	msec	-	-	-

TABLE V: Data fields of message format *SRM*

sending vehicle. As next field it contains the referrer id, which is the identifier of the message to which this SRM is the response. Selection field contains the response that has been chosen by the driver.

The driver can exit the parking garage and use the onboard navigation system outdoors with the normal GPS sensor again. The *Leave* message eventually releases the collaborative session again.

IV. EVALUATION

Having defined a comprehensive architecture and communication protocols for indoor parking scenarios, the key question is how much communication and sensing hardware needs to be deployed in the parking garage. Based on our previous works, we are able to determine the amount of hardware required to equip indoor parking spaces. With respect to DSRC, we deployed an 802.11p NEC Linkbird (v.4) RSU into our underground parking testbed [19]. The transmission power has been set to 21 dBm and an 8 dBi omnidirectional antenna was used. The main goal of this investigation is to find out how much area can be covered by a single RSU, especially considering the high 802.11p operational frequencies in the 5.9 GHz band which are associated with relatively strong signal attenuation. Given the assumption that vehicles (with externally mounted antennas) need to at least achieve a received signal strength (RSS) of -70dBm for a reliable and stable connection, a single RSU can cover $2150m^2$. Figure 4 depicts a heatmap of the signal distribution in the parking environment.

	Hardware	
	RSU	*Camera*
Coverage	2150 m^2	650 m^2
Power consumption	5 W	7 W
Cost	1000 USD	600 USD

TABLE VI: Hardware requirements for equipping indoor parking spaces, 802.11p RSU (Linkbird v.4) and camera (AXIS Q1604) with Deep Learning detector.

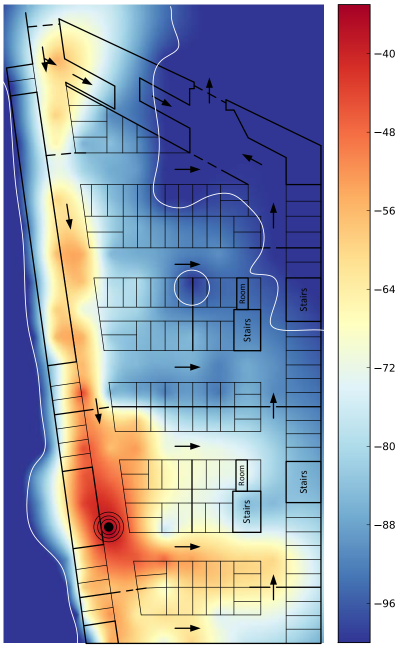

Fig. 4: Coverage of a single 802.11p NEC Linkbird RSU in an indoor parking environment [19].

Moreover, the area covered by a single camera and the range of the image processing algorithms is a critical cost factor for the overall system. The achievable range depends on multiple factors: Camera resolution and light sensitivity, illumination of the environment, image processing algorithms, computational performance as well as required positioning accuracy. We have used AXIS Q1604 (FW: 5.40.3.1) network cameras, at a mounting height between 1.90m and 2.80m within a tolerance of 0.50m to the lane center. The viewing direction is parallel to the driving direction and the cameras provide images at 1280x720px at a rate of 50Hz. Our initial vehicle detection system relies on Haar-like feature detectors [2][22] whereas the new detection system uses Deep Learning [23]. Given the selected AXIS cameras and the requirement to achieve a positioning accuracy better than GPS (i.e. sub-meter accuracy), a single camera covers a distance of $30m$ or $50m$ corresponding to an overall area of $390m^2$ and $650m^2$ for the Haar-like feature and Deep Learning approach respectively. Table VI summarizes the coverage area, average energy consumption and cost for both a single camera and RSU. Another cost factor is a backend server infrastructure where vehicle detection as well as tracking algorithms are processed. A wired network infrastructure is also required to connect the RSUs and cameras with the backend.

V. SUMMARY

In this paper we presented an approach to enable fully automated driving in an enclosed parking garage (valet parking) using DSRC with ETSI ITS G5. Our eValet testbed utilizes infrastructure-based cameras to detect and localize vehicles in and around the garage.

We use the Collaborative Maneuver Protocol for session-based synchronized communication over an ad-hoc wireless environment. By mapping function behaviour in a distributed state machine, the various aspects of a real-world valet function are synchronized between vehicle and infrastructure. The vehicle uses a handover zone to transfer control from driver to vehicle and to switch to external localization for the following drive in an underground parking garage. We propose a set of messages and a protocol for valet parking over IEEE 802.11p with CMP.

In a detailed evaluation, we show the range of 802.11p in a real-life parking garage and make estimates on necessary infrastructure to scale up to larger parking environments. In essence, this intelligent infrastructure has been enabled by recent technological advances in sensors, communication infrastructure and computational resources. The improved detection range of the Deep Learning approach is a prime example of how rapid technological advances lead to massive synergy effects which improve the economic feasibility of existing applications and enable applications that were previously impossible.

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