Vehicular Communications in the V-Charge Project

(Extended Abstract)

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***Abstract*—Future requirements for drastic reduction of CO_2 production and energy consumption will lead to significant changes in the way we see mobility in the years to come. However, the automotive industry has identified significant barriers to the adoption of electric vehicles, including reduced driving range and greatly increased refueling times. The V-Charge Project, funded by the European Commission, seeks to address these problems simultaneously by developing an electric automated car, outfitted with close-to-market sensors, which is able to automate valet parking and recharging for integration into a future transportation system. In this paper, we describe the research challenges associated with providing a wireless Vehicle-to-X (V2X) communication infrastructure for V-Charge-enabled parking areas.**

I. INTRO

As part of their "Europe 2020" program, the European Commission has outlined a number of ambitious targets for Europe to meet by the year 2020[1]. These targets address a wide range of social, environmental, and economic issues. Part of the strategy is to address the problem of climate change, to reduce greenhouse gas emissions, to move toward renewable sources of energy, and to increase energy efficiency. One aspect of this challenge will be the reduction in reliance on fossil fuels and the move to electric motor vehicle transport. However, the automotive industry has identified significant barriers to the electrification of vehicles, including reduced driving range and increased refueling times [1]. The European V-Charge Project seeks to address these problems simultaneously by developing an electric automated car, outfitted with close-to-market sensors, which is able to automate valet parking and recharging for integration into a future transportation system. [2]

To illustrate the vision of V-Charge, we use the following smart car system scenario: A traveling person seeks to catch a flight, possibly having a tight schedule. At large transportation hubs like airports, the process of finding comfortable parking close to one's departure terminal is usually quite cumbersome and time-consuming. V-Charge improves this situation significantly, allowing the driver to stop the car at a designated drop-off zone in front of the terminal and to directly proceed to the departure gate. Meanwhile, a back-end server, called the V-Charge ParkingManager [3], which is in charge of the efficient parking resource management, provides the vehicle with relevant mission information, such as an assigned charging station or parking spot, a map of the premises, etc., via Vehicle-to-Infrastructure (V2I) communications. These data allow the vehicle to autonomously navigate and maneuver to its assigned target destination. Similarly, when the driver returns, he can remotely command the vehicle to the pick-up zone by issuing an according request to the back-end using his smartphone.

Fig. 1. The initial experimental platforms for the V-Charge project.

This implies three major fields of research: (i) *vehicle functionality*, onboard localization, detection of static and dynamic obstacles, and on-board planning using only close-to-market sensors, (ii) *logistics*, optimal scheduling of charging stations and assignment of parking spots, and (iii) *infrastructure*, development of a secure and reliable communication framework to store and share a database of information about the parking area. [2]

This paper will present an overview of the research fields (ii) and (iii) of the V-Charge project, with a focus on the communications aspect. The experimental platform consists of two VW Golf, shown in Fig. 1, which have been modified to support fully automated driving using only close-to-market sensors.

II. PARKING MANAGEMENT

Since the number of charging stations at large parking areas, due to cost reasons, will be limited, the search for an available (and charging-capable) parking spot will be typically even more complicated and time-consuming for electric vehicle (EV) drivers than for drivers of internal combustion engine (ICE) cars. V-Charge therefore provides an automated parking and charging system, based on a central back-end server which is in charge of an efficient parking resource management. It also provides each vehicle with relevant mission information allowing it to navigate to its assigned target destination. Since the developed management algorithms are generally applicable, however, they are also beneficial for non-autonomous (e.g., human valet parking) or non-electric usage scenarios.

To enable this system functionality, two main contributions to the management and infrastructure part of the project are

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[1] http://ec.europa.eu/europe2020/europe-2020-in-a-nutshell/targets/index_en.htm

made. First, the abovementioned concepts for efficient parking management are developed. Based on driver requirements, e.g., prospective parking time, current battery charging level and required travel distance, the V-Charge ParkingManager [4] assigns (schedules) available parking resources, such as regular parking spots and, in particular, scarce charging stations to connected vehicles. Requirements for charging station scheduling as well as a short overview of first evaluation results are given in [5]. Several scheduling algorithms have been developed and evaluated [3] in detail in a dedicated simulation environment, considering different usage scenarios. For the simulation setup, real-world parking statistics obtained from Hamburg Airport and the City of Braunschweig, Germany, are used.

Second, a framework for V2I and Vehicle-to-Vehicle (V2V) (both terms are often subsumed as V2X) communications is developed and described in Section III. This framework enables the distribution of mission information to connected vehicles. Mission information includes assigned charging stations or parking spots, a digital map of the premises with marker and docking positions at charging stations, etc. Sensor data aggregated by roaming and parking vehicles, e.g., road conditions and parking occupancy (relevant in mixed-mode scenarios), are transferred back to the server, where they are merged with the central map. Further, the framework provides global system monitoring and remote debugging. Of course, state-of-the-art security and trust concepts are factored in, as described in Section IV. Driver interaction (status check, drop-off, pick-up) is realized via mobile user devices (smartphones). In Section V, we show how to collect network connectivity information and how to use it for advanced parking management decisions.

III. V2I Communications Architecture

All in-vehicle modules, such as sensors, localization and on-board planning, share information in the form of broadcasts or point-to-point connections using the Data Distribution Service (DDS) middleware. Therefore, we examined the feasibility of exploiting the middleware on the wireless link for V2I communications (as suggested in [4]). This would afford a homogeneous protocol stack and possibly synergy effects between project partners. Our evaluations, however, have shown that in our usage scenarios, DDS on the wireless link has some drawbacks such as lack of addressing specific nodes, high overhead for implementing security, and lack of multi-hop support. Thus, DDS will be used both on the vehicle and server side, but not between them.

Instead, an efficient and powerful framework based on a Delay-/Disruption-Tolerant Network (DTN) [6] is being developed for V2X communication. Because of the limited communication range of wireless radios and the highly dynamic structure of Vehicular Ad Hoc Networks (VANETs), often there is no end-to-end path between any two network nodes willing to exchange data. DTNs overcome this intermittent connectivity with a store-carry-forward approach and therefore do not require stable links. In a DTN, messages are stored at a node as long as there is no next hop available for forwarding a message. The node carries the message along its way and forwards it as soon as a new connection for forwarding becomes available. Additionally, as an overlay network, DTNs can bridge different network technologies (e.g., IEEE 802.11 and IEEE 802.15.4), ensuring information exchange across network limits and thus reaching a larger set of potential communication partners.

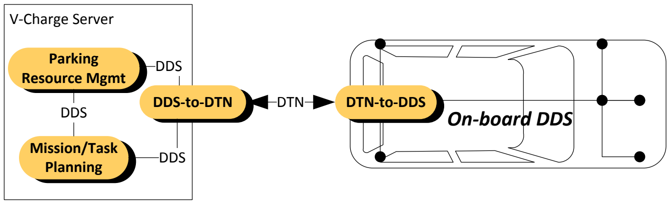

Fig. 2. Mission control architecture. A disruption-tolerant network and the DDS middleware are used for V2I and intra-component communications, respectively.

Although originating from interplanetary communications, DTN seems more practical than DDS for the transmission of mission-related traffic. For this purpose, we utilize IBR-DTN[2] [7], a lightweight and modular Bundle Protocol [6] implementation. Due to the integrated routing modules, no direct connection between the source and the individually addressable sink of the data is required—the routes can be determined dynamically. While assuming direct connections between nodes in the parking lot as the default, vehicles or stationary nodes can also be used as relay stations to extend the network coverage, as described in Section V. Moreover, data can easily be encrypted, but still be routed via other nodes. An overview of the resulting communication architecture is given in Fig. 2.

IV. V2I Security

An interesting research challenge in the context of vehicular DTNs is the question how drivers can securely register their vehicle with the V-Charge service and deploy keys for securing V2I communications [8]. By means of a smartphone-based registration and key deployment process for V2I communications, we are able to achieve a high degree of user independence from third parties, since nobody but the owner (not even the OEM) ever possesses the vehicle's private key. Further, our open and easily auditable protocol warrants user trust in the underlying cryptographic principles. Although we propose a solution aiming at the V-Charge project, our concepts are more generally applicable. For instance, any vehicular cloud service relying on a Public Key Infrastructure (PKI) could use the same process, since we provide an application-independent means for secure key deployment without entrusting the service provider or a third party with the private key. Moreover, the proposed solution is applicable to vehicles that come pre-deployed with the required communication technologies as well as refitted ones. Besides local ParkingManagers (PMs) communicating securely with vehicles via DTN, the V-Charge service consists of several central components: (a) the CustomerManager, (b) the Authorization Server, and (c) the DTN Certificate Authority (CA).

(a) The CustomerManager [4] provides registration functionality and all necessary service methods (pick-up, drop-off, status checking) via RESTful Web services that are being interfaced by the V-Charge smartphone application. All methods of

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[2] http://www.ibr.cs.tu-bs.de/projects/ibr-dtn/

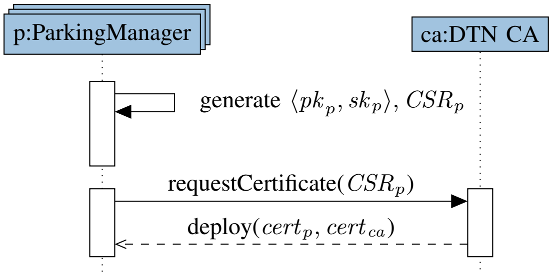

Fig. 3. Deployment of certificates issued for local ParkingManagers.

the interface are protected by the OAuth 2.0 standard [9]. (b) A central OAuth Authorization Server handles all OAuth sessions and provides verification methods. The connection between smartphone and the RESTful Web services itself is secured by SSL. (c) The DTN CA manages certificates deployed to all participants in the DTN, i.e., PMs and vehicles.

As depicted exemplarily in Fig. 3, a public/private key pair $\langle pk_p, sk_p \rangle$ is generated by each PM p. The DTN CA processes p's Certificate Signing Request (CSR) after it physically received it from p and sends back an certificate $cert_p$ signed with the CA's secret key sk_{ca}. After $cert_p$ has been deployed on p, vehicles equipped with the DTN CA's root certificate $cert_{ca}$ can verify if Bundles are affiliated to a PM (i.e., signed with sk_p) and are thus allowed to issue control commands (i.e., drop-off, pick-up). For more details, the interested reader is referred to [8].

V. CONNECTIVITY MAP

In order to allow the central parking management system to efficiently and safely communicate with vehicles and to send them to assigned parking spots and charging stations, it is paramount to ensure that vehicles will not be sent to areas of the parking area/garage where the reception of the wireless signal is too weak or where there is no reception at all, as we have previously described in [10]. Otherwise, a vehicle sent to such an area might not be able to communicate with the parking management system anymore and will thus not be able to receive further mission commands—it would require manual intervention to retrieve it. Further, depending on the operational use case, there are extended requirements to the communication link that go well beyond of what a simple "reception/no reception" evaluation is able to achieve. For instance, some use cases (emergency stop, operating data monitoring, etc.) require a certain minimum Quality of Service (QoS) level in terms of reliability, latency or throughput.

The concept of the Connectivity Map [11] is used to meet these requirements. The basic idea is that vehicles in the parking area perform measurements in terms of current communication properties as a byproduct of V2I communications. The collected data, exemplarily depicted in Fig. 4, can be transferred and stored on a central back-end, allowing the estimation of the network characteristics for other vehicles. Therefore, areas where the QoS requirements cannot be met or where "white spots" occur can be determined in advance to avoid them in future mission planning or to use the network characteristics for sophisticated scheduling.

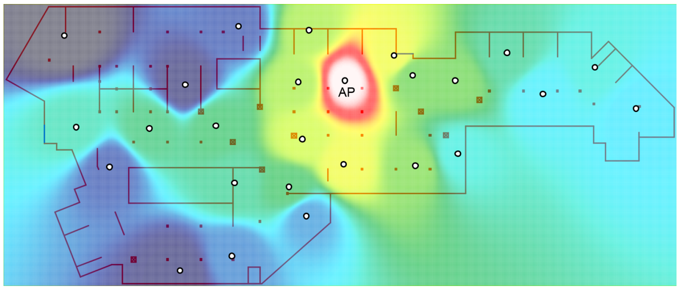

Fig. 4. Overlay heatmap of the RSS in an indoor scenario.

In the following, we will present some use cases for the connectivity map which allows us to create a cost- and energy efficient system.

A. Dynamic Optimization of Utilization of Infrastructure Components

The installation of (wired) infrastructure for providing network coverage of parking garages or large parking areas near fairgrounds is quite cumbersome and expensive. Solar-powered and battery-supported access points with a wireless (directional) uplink can be used to simplify the installation. Energy restrictions, however, require taking efficiency and energy consumption into account. Options are to power those nodes up only when they are absolutely needed or switching between different links for communication, depending on the application's needs. For example, a radio with low energy requirements, e.g., IEEE 802.15.4, may have a small (but in some cases sufficient) data rate, while IEEE 802.11 can achieve a higher throughput and larger communication range. For each radio, power control settings should be used to ensure a stable communication link while keeping the transmission power as low as possible.

The PM [4] makes decisions on the vehicles' positions in the car park and thus has the possibility to position them in a cluster, for instance, which allows wireless infrastructure components in deserted areas to be kept powered off.

B. Multi-Hop

Data on the network quality like signal strength or bandwidth sensed by vehicles in the parking area can be used to collect real-time, real-life information on the network status. Radio failures of single infrastructure components can be detected and according countermeasures can be taken. For example, a supervisor can be informed and the scheduling modules can handle the area as a (temporarily) white spot and navigate vehicles around the affected region.

In traditional V2I systems, vehicles in white spot areas could not be addressed by the back-end. In our system, however, the multi-hop features of the DTN software can be used to establish a communication with those cars. Thus, they can be requested to move to another parking spot with network coverage, for example.

C. QoS-based Parking Management

In [4], it was shown how a parking management system can accommodate different (and contradicting) user requirements such as estimated parking time, state-of-charge for electric vehicles, etc. The Connectivity Map enables us to extend this system by making advanced parking management and scheduling decisions based on the abovementioned QoS requirements.

For parked vehicles, different QoS requirements can be defined. If a user wants large amounts of data such as media files or digital maps uploaded to his vehicle during the stay, it should be parked in high throughput areas. When all data transfers are finished, the car can be automatically moved in order to free high-connectivity parking spots. At all times, it has to be ensured that a basic connection to each vehicle can be established. Using multi-hop communications, this may be even ensured for white spots by adeptly parking vehicles nearby and using them as relays. Overall, this approach enables us to minimize infrastructure costs, e.g., Access Points (APs) installations and maintenance effort.

VI. CONCLUSION

In this paper, we have presented an overview of research challenges in the V-Charge project, with a focus on the communications aspect. This includes a DTN-based V2X communication architecture, that allows us to facilitate IBR-DTN's built-in features in order to increase the stability and reliability of the wireless link. Moreover, security challenges in the V-Charge system have been addressed. We have described our vision of advanced parking management decision support.

ACKNOWLEDGMENT

The project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement Number 269916.

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