Abstract. Highly automated vehicles will change our personal mobility in the future. To ensure the safety and the comfort of their passengers, the cars have to rely on as many information regarding their current surrounding traffic situation, as they can obtain. In addition to classical sensors like cameras or radar sensors, automated vehicles use data from a so called High Definition Street Map. Through such maps, the vehicles are provided with continuous updates regarding their future driving environment on a centimeter accurate level. The required amount of data, which is necessary therefore, motivates the development of more efficient data transmission concepts. In this paper we present HD-Wmap an extension of our previous work the Dynamic Map Update Protocol. Based on each vehicle's current context the Dynamic Map Update Protocol achieves a highly data efficient transmission of map updates compared to existing distribution approaches. HD-Wmap further reduces the costs of such transmissions by enabling map data to be shared via ad hoc communication between the vehicles. To evaluate the capabilities of HD-Wmap we perform a first simulation of the morning commuting traffic within the area of Cologne, Germany. In this scenario HD-Wmap achieved an ad hoc map data off loading quota from cellular networks of up to 25.5%. These results demonstrate the gains of our approach to realize efficient map distribution via ad hoc communication, releasing load from wireless Internet access networks.

Intelligent Offloading Distribution of High Definition Street Maps for Highly Automated Vehicles

Florian Jomrich[1 3], Aakash Sharma[2], Tobias Rückelt[3], Doreen Böhnstedt[3] and Ralf Steinmetz[3]

[1] Adam Opel AG, Bahnhofsplatz, 65423, Rüsselsheim, Hessen, Germany
e-mail: `florian.jomrich@opel.com`
[2] Department of Computer Science, UiT: The Arctic University of Norway, Hansine Hansens veg 54 Breivika, 9019, Tromsø, Norway
e-mail: `aakash.sharma@uit.no`
[3] KOM Multimedia Communications Lab, Technical University of Darmstadt, Rundeturmstr. 10, 64283, Darmstadt, Hessen, Germany
e-mail: `name.surname@kom.tu-darmstadt.de`

1 INTRODUCTION

To ensure the safety and the comfort of the passengers of future highly automated vehicles, researchers and engineers let the cars rely on a multitude of different sensors. Besides onboard systems like cameras, radar sensors or lidar scanners [46], the vehicles further rely on an additional ”virtual” sensor, the so called High Definition Street Map (HD-Map) [22]. This map is a centimetre accurate [40] virtual representation of the vehicle’s surrounding world. With the aid of this detailed information, the autonomous cars can plan their future driving manoeuvres in advance. The capabilities of the map thereby extend the sensing range of the car’s on-board systems [2],[4] and provide an additional independent view on the current traffic situation. This is especially helpful for modern localisation and perception algorithms [20], as they are able to verify their personal sensing information with existing map material [7]. Nearly all companies and research groups, which are involved into the topic of highly automated driving, rely upon the HD-Map to further enhance the driving capabilities of their own autonomous vehicles. Examples therefore are Google [28], HERE [42], TomTom [44], Continental [13] and car manufacturers like BMW [2], [6] and Tesla [34]. Due to its high precision and its high dynamic information content about the current surrounding traffic situations, the HD-Map gets outdated very quickly. Even standard navigation map material is outdated after a short period of time and profits from regular updates [35]. With the HD-Map, this situation is becoming even more critical. Update processes, which could wait for months now have to be finished within minutes. These kind of updates are only possible through a continuous datastream, which lets Hammerschmidt[13] speak of a ”living map”. Thus, currently existing update procedures for standard navigation maps are not feasible anymore in the context of HD-Maps. New concepts have to be investigated to let autonomous vehicles fully rely on HD-Maps. Within our previous work we addressed this problem by the presentation of the Dynamic Map Update Protocol [21]. The protocol enables the autonomous vehicles to receive map updates specifically for their personal requirements based on their own current and future driving context. Within the evaluation of this work, we show that the protocol outperforms existing state of the art map update approaches in terms of data efficiency and processing load.

This current work now represents an extension of the protocol from [21] to further reduce the costs for update transmissions and the general network load. The protocol itself has been initially designed to synchronize with a centralized map server. All vehicles communicate individually with this server, when requesting their updates via a cellular communication interface. This, however, introduces high transmission costs for the map updates and requires permanent access to a map server, representing a (potential) single point of failure. Within the scope of the present paper, we extend the protocol to enable vehicles to dynamically share already received map updates between each other via ad hoc network communication. This extension, which we call HD-Wmap , reduces cellular network transmission costs and also improves the load at the centralized map server, as it only has to provide map updates where no direct ad hoc data exchange could happen in advance. The general technique for offloading data transmissions on different communication channels is a well established paradigm, that has been evaluated in many different publications for the vehicular context (see section 2.2). To the best of our knowledge, the presented work is the first, that adapts this concept for the distribution of navigation map material required for autonomous driving via ad hoc communication between the vehicles.

The outline of the remaining paper is described in the following. In Section 2, current state of the art map update concepts are discussed. Furthermore we give an introduction to related data-offloading approaches. Afterwards, the general working principle of the Dynamic Map Update Protocol is summarized in Section 3. This helps to follow the further extensions of the protocol, introduced in Chapter 4. In Chapter 5 we give an overview about our new and adapted simulation scenario, which reflects the morning rush hour traffic of the city of Cologne with up to 40.000 vehicles. Based on this scenario, the obtained results of the extended Dynamic Map Update Protocol are presented in comparison to a solely centralized approach of the protocol. We conclude the paper with a summary of the presented adaptation and the achieved improvements, as well as an outlook regarding future work.

2 RELATED WORK

First, we give an overview about related work in the area of map updates, which provides the basis for the development of our Dynamic Map Update Protocol. In the second section we introduce related work in the domain of ad hoc communication and data offloading, which is related to our new extensions of the protocol.

2.1 Research on map updates

Electronic navigation devices for vehicles have been introduced to the market more than 25 years ago [19] and are now a frequently used feature in series. Most navigation systems can be grouped into one of two different categories: offline and online navigation. Most of the built-in car navigation devices are offline systems. They can operate completely independent of any kind of data connection, as they solely rely on an internal storage space when calculating the route to a given destination. This storage contains the complete map data in an efficient binary format. It enables fast read access and, therefore, improves significantly the performance of routing algorithms. This advantage, however, comes at the cost of a major disadvantage for the rapidly outdated HD-Maps. The binary map cannot be updated via partial replacements of the data, as Min et al.[31] expressed in their work. Map updates must be provided as a unit of the whole map material in a single file. This might be one of the reasons why mapping companies only provide an updated version of their own map material after several months (e.g. Tom-Tom[4]). This is an inacceptable circumstance in the context of HD-Map material, because it has to be updated within minutes to ensure the function and safety of the autonomous vehicle.

In contrast to offline systems, online navigation systems do not have to rely on an own large internal storage space. Such systems are, for example, represented by current smartphone applications like Google Maps[5]. Each time a new route is calculated, they request the newest map material from a dedicated map server by wireless data transmission. Thus, this approach ensures that the map material is always up to date. This, however, requires a lot of redundant data to be transmitted each time a route is calculated. This is especially true if certain routes are requested frequently (e.g. the owner's daily commute to work). In the context of HD-Maps with their high degree of detail and thus increased size, redundant data transfer even becomes a more severe problem. Unlike a human driver the highly automated vehicle has to always rely on the information provided by the HD-Map and request its route guidance for every trip. Furthermore, it might not always be the case that a data connection is available, which will render the online navigation unusable.

In conclusion, both approaches, offline and online navigation, contain certain disadvantages.

To address these problems there has been a strong interest in research. Several different approaches enabling so called partial and incremental map updates have been published [9], [5], [30], [3], [27], [31], [24].

The general idea behind a partial map update is to divide the whole map material into smaller chunks, so called map tiles. These map tiles are then further addressed as individual maps that can be updated independently from each other.

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[4] http://uk.support.tomtom.com/app/content/id/9/locale/en_gb/page/4

[5] https://maps.google.de/

Incremental map updates realize a sequential distinction of the map materials construction steps over time. Through special data structures (e.g. databases like PostgreSql[6]); the history of changes within the map can be reproduced. This enables the map server to provide highly data efficient map updates, which only contain the map changes required by the vehicles. Both approaches are usually combined to partial, incremental map updates. Those updates are then provided through a wireless connection (e.g. cellular) to the vehicles. A reference example of such a system is the work by Min et al. [31]. However partial and incremental map updates introduce further challenges. A main challenge is to ensure the consistency of the map material after an update has been conducted, as stated by Asahara et al. [3]. Roads that traverse different map tiles might become unroutable if a map tile update causes inconsistency. To solve this problem the authors propose a procedure that checks the neighbouring map tiles regarding consistency. Engineers of Hitachi Automotive Systems, Ltd. [14] improve this approach further as they specifically generate connected map objects that ensure the consistency of the updated map. This prevents situations in which the update of one single map tile after another, as suggested by Asahara et al., would lead to a cascade of updates of the surrounding map tiles.

In contrast to the other presented publications, the ActMap Project [5] conducted by Bastiaensen et al. suggests to update only the map tiles on the car's current route.

As it minimizes the amount of necessary map updates the most, we considered the approach by Bastiensen et al. as the reference algorithm for comparison with our own Dynamic Map Update Protocol.

The design of the Dynamic Map Update Protocol has been influenced by all the aforementioned concepts. Our protocol enhances them by enabling specific map updates regarding the context of each individual vehicle as presented in Section 3 and in [21].

2.2 Data offloading via ad hoc communication

HD-Wmap improves the protocol from [21] further by leveraging the capabilities of vehicles to create so called Vehicular Ad hoc Networks (VANETs).

Our approach, as introduced in detail in Section 4, relies on the capability of the cars to communicate directly with each other. Technologies introduced in the 802.11p WiFi standard [32] allow them to exchange data, when they are in the transmission range of each other.

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[6] https://www.postgresql.org/

In the context of mobile vehicular networks a strong research effort has been conducted to leverage this functionality. Many publications propose different approaches to offload data streams from costly cellular networks to free wireless communication.

Several of the existing approaches [11], [25], [29] therefore rely on the deployment of dedicated road side units in the roaming area of the vehicles. These units are able to communicate with the cars via WiFi technology. They are directly connected to the Internet via a cable connection to offload the network traffic. In our opinion, the wide deployment of such units (as it would be required for the deployment of map updates) is highly questionable, because they introduce additional installation and maintenance costs. Thus, the advantage of these road side units, compared to the already existing towers of the cellular network, is questionable. The work by Lee et al. [23] tried to improve this situation by only relying on the deployment of so called relay nodes for their offloading approach. In contrast to the road side units, these nodes do not possess a direct connection to the Internet, but are used as static nodes to hold and forward data between the vehicles. We argue that this still involves additional costs, which should be avoided. In contrast to the mentioned approaches, our extension of the Dynamic Map Update Protocol therefore relies solely on the direct ad hoc communication between the cars, as it does not involve further costs regarding any kind of additional hardware infrastructure.

Lee et al. stated that the installation of relay nodes is a necessary requirement, as the probability of two vehicles meeting each other with the same data requirements, which they can share, might otherwise be too low. We argue that this is especially not the case for map data updates. People tend to roam in their local neighborhood more than traveling far distances [33]. Thus, the chance to meet a vehicle that has already obtained required map data, is getting more and more probable when the car advances to this area.

To the best of our knowledge, we are the first who present an approach that disseminates map data between vehicles via ad hoc communication. Related papers propose ad hoc communication for map data sharing as a potential application [12], [38], [39] without getting into further detail or presenting a specific solution approach, as we do in our paper.

3 GENERAL WORKING PRINCIPLE OF THE DYNAMIC MAP UPDATE PROTOCOL

For better understanding of the performed enhancements of our previous work, we briefly summarize the general working principle of the Dynamic Map Update Protocol. For further details we refer to our previous work [21].

The Dynamic Map Update Protocol bases on the existing map update concepts presented in the Related Work section. It improves these concepts by introducing contextual relevance into the update process. In contrast to a human, a highly automated driving vehicle always has to rely on data detailing a specific given road when driving. The start and the destination of a trip are always known before the trip or have to be assumed, for example by a most probable path calculation as explained by Ress et al. [37] or Burgstahler et al. [10]. The Dynamic Map Update Protocol leverages this knowledge about the travelling path to decrease the amount of data to be transmitted when requesting a map update. To achieve a low transmission overhead, as offline navigation systems and the high up-to-dateness of online navigation systems, the protocol establishes a hybrid navigation approach as illustrated in Figure 1. We assume that the highly automated vehicle has limited persistent storage to save a certain amount of map material for its navigation purposes. Thus, it is not dependent on an always available data connection. However, to ensure that the car can rely upon the most up to date map material at every time, it is equipped with a cellular communication module. Through this module, the car checks initially at a dedicated map server if its map tiles for its current route are up-to-date. Therefore, it calculates the desired route based on its stored map material (that might be outdated). In a second step, the vehicle transmits the start and destination points of its route, as well as the used map tile IDs and their version to the server. Then the server compares its personal map database with the one of the car. In the now following update step, in contrast to Bastiaensens [5] map update approach, our protocol does not directly update all the map tiles, which are identified as outdated along the path of the vehicle. As a main contribution of the protocol and illustrated in Figure 1 the server is able to distinguish between map updates which are mandatory or optional for the vehicle's route. Mandatory map updates directly influence the current route on which the car should reach its destination. For optional updates, this is not the case. These kind of updates might be changes within the map tile that concern streets, which the car does not use on its planned route. Successively, the server provides the mandatory updates to the car and informs it about the optional map updates. Thus, the car can "decide" if it wants to request those map updates as well or delay their transmission to a later point in time. That way, the Dynamic Map Update Protocol is able to reduce the amount of transmitted map data significantly.

To distinguish between individual map tiles, the Dynamic Map Update Protocol uses the indexing structure of Geohashes [43]. A Geoshash is a string specifically generated to identify a certain geographic area in the world. Its length denotes the size of its addressed area. We leverage this property of the Geohash to further optimize the updating procedure of our protocol. Inspired by the general working principle of modern routing algorithms [31], we distinguish the map material into different layers. Depending on their personal type, streets are then added to one of those layers. Highway streets for example span a longer distance to interconnect cities, compared to smaller urban streets (see Figure 2). Thus, for the exemplary evaluation of the Dynamic Map Update Protocol in [21] highway streets are grouped together in map tiles of larger size (assuming a Geohash size of 4 resembling a covered area of 40km x 20km), as illustrated in Figure 2. In contrast urban streets are composed in smaller map tiles (assuming a Geohash size of 5, which covers an area of about 5km x 5km). The concept of different map layers allows the Dynamic Map Update Protocol to provide specific updates regarding the current streets on which the vehicle is travelling, neglecting unnecessary information. Furthermore the protocol overhead to exchange map material is reduced in this way.

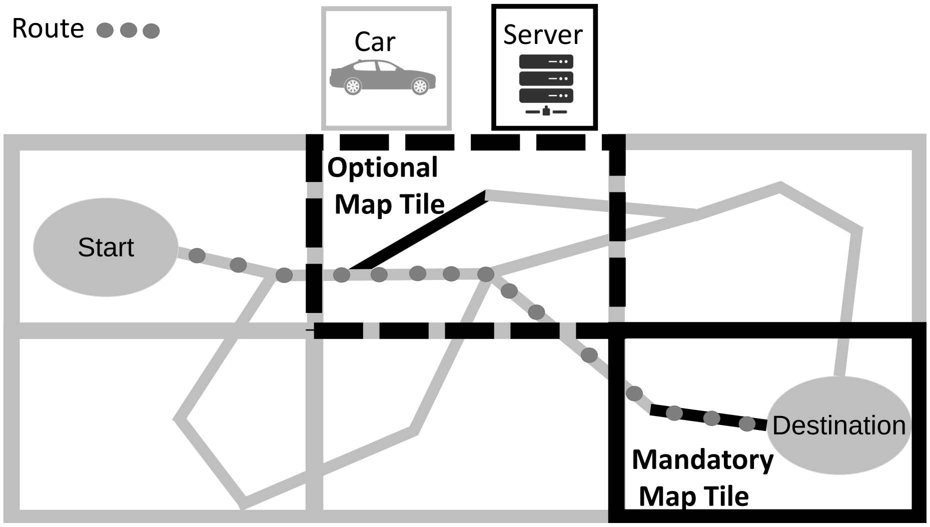

Fig. 1. Example for the general principle of the Dynamic Map Update Protocol [21].

4 IMPROVING MAP DATA DISTRIBUTION THROUGH AD HOC TRANSMISSION OFFLOADING

The concept of the Dynamic Map Update Protocol [21] is based on the assumption of a bidirectional exchange of map data between a

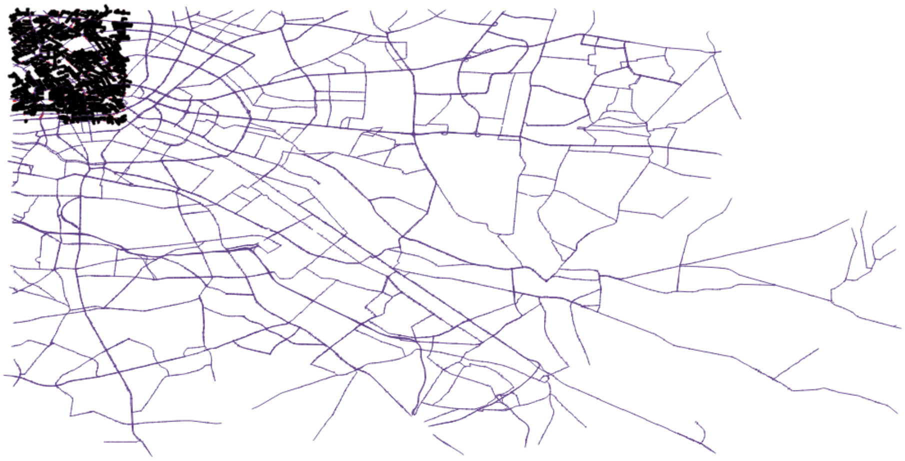

Fig. 2. Size of a city street layer map tile (bold) in comparison to a highway layer map tile [21]). ©OpenStreetMap contributors

vehicle and a central map server (in the backend). Both communicate via a cellular network connection. This approach is feasible as long as the backend server operates and the cellular network is available. Both preconditions, however might not always be given. The backend server might fail sometimes in the future. Also, the cellular network is not completely fail-safe and the network coverage of certain areas [36] is an additional problem. This is due to the effect that cellular network expansions focused on areas with a high population density to achieve the highest possible revenue for the network providers. Thus, street networks are often insufficiently covered. Highly automated vehicles now change these requirements. To overcome this insufficiency, we propose our new map data offloading schemata HD-Wmap. HD-Wmap is an extension of the Dynamic Map Update Protocol that enables the vehicles to not only exchange map data with the map server, but also individually between each other. We assume that future HD-Maps will be distributed as a paid cloud service [8]. As stated previously, it is otherwise not possible to maintain the automated driving service provided by such a map due to the high frequency of map updates. Therefore, map selling companies will highly profit by relying on ad hoc communication as an additional distribution channel between the vehicles in addition to the already proposed cellular transmission from a backend server [21], which is hosting the map. Ad hoc communication will significantly improve the service quality and reliability of such map data providers. This is especially true in scenarios of high load like in a traffic jam or the daily rush hour. Direct communication will then help to reduce the load on the cellular networks by lowering their costly data traffic. Also the processing load on the map server will be reduced as the cars can share already provided map material instead of requesting it several times. Furthermore, ad hoc communication enables the distribution of map updates even if there is no cellular infrastructure available. To realize the sharing of map data HD-Wmap relies on technologies assumed to be available in highly automated vehicles as presented in the following.

4.1 Compatibility to standards

Different technologies exist to enable ad hoc communication between vehicles, e.g. the WiFi-based 802.11p [32] standard or an upcoming extension of the LTE cellular communication, the so called LTE V2X [41]. In the following, we explain the general principle of HD-Wmap based on the 802.11p standard, as it is the more advanced standard. LTE V2X provides similar functionalities, that have been inspired by the discussions related to 802.11p.

To be able to realize a certain set of applications for advanced driver assistance systems [15] as specified by the European Telecommunications Standards Institute (ETSI)[7] the vehicles continuously exchange standardized messages with each other. This includes Cooperative Awareness Messages (CAM)[16], Service Awareness Messages (SAM)[17] and Decentralized Environmental Notification Basic Services (DENM)[18]. CAMs are transmitted to inform the surrounding vehicles about the transmitting vehicles current position, speed and further direction. They are continuously broadcasted with a rate between 1 and 10 Hz depending on the currently present overall load on the data channel. SAMs are transmitted to inform vehicles about certain application services availability. Furthermore, DENMs supply vehicles with the capability to inform others about certain events currently experienced in the traffic. This could be for example an information about an ongoing construction side. All these messages include optional containers that facilitate the extensions required by HD-Wmap. Thus, we propose to extend one of these messages to include the necessary additional information required to initiate the map data sharing procedure between the vehicles, as explained in the following sections.

4.2 Home zone concept

Highly automated vehicles most frequently need the map material of the routes on which they have to drive regularly. These are for

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[7] http://www.etsi.org/

example the commuting routes of their owners, the local neighbourhood and nearby towns. These areas are therefore considered as home zone in the following. The home zone is assumed to be updated frequently at the beginning of each trip, including all HD-Map layers, e.g. by downloading updates for it at home through a WiFi connection. This complete information of the area differs from the partial and layer-specific updates of vehicles from apart. As home-zoned vehicles roam in this area the most, they are predestined to share their data with others. Thus, home zones provide the backbone for efficient map distribution via ad hoc communication, releasing load from wireless Internet access networks.

4.3 Procedure of HD-Wmap to offload map data

```
HD-Wmap procedure actions:
1.) Check which updates are required for the current trip.
Gather necessary Geohashes and tile versions from the backend server.
2.a) If (distance to map tile > x) request it via ad hoc.
  b) Else download it via cellular.
3.) Answer requests, if data is available in the own internal storage,
e.g. recently downloaded or as part of the home zone.
```

Algorithm 1: Actions performed in a map exchange by HD-Wmap .

The working principle of HD-Wmap is summarized by the procedure actions in Algorithm 1. We explain them in this section based on an example as illustrated by the Figures 3 and 4. In the example two different cars a sedan and a cabriolet each drive an own trip (see Figure 4). The home zones of the vehicles are assumed to be the areas, which include the two most left, respectively the two most right map tiles of the example map database as shown in Figure 3. As first step (1.) in Algorithm 1) in the procedure of HD-Wmap each vehicle requests the mandatory and optional updates of map material for its current route from the dedicated update server. In our example these are two mandatory map updates, one for each car, indicated by black color in Figure 4. The vehicles first try to gather those updates via an ad hoc transmission (2.a)). A certain time is necessary for a car to be able to obtain an outdated map tile via ad hoc communication. Thus, the car has to start the request process for it at a certain distance (e.g. several kilometres) in advance, before it reaches this location. Therefore the vehicle is sending a request message to its neighbours with a certain frequency. We consider such a request as an extension of one of the already standardized messages as explained in section 4.1. The additional container to be added in the message just has to include two additional parameters, the Geohash ID of the requested map tile and its required version status.

If one of the cars within the proximity of the requester has obtained this map tile, it starts to provide its data to him (3.)). This is for example the case for the sedan, as the cabriolet can share map data of its home zone when both cars meet in the upper middle map tile, as illustrated by Figure 4. The vehicles themselves are not capable to provide smaller delta updates like the map data server, because they cannot store the whole version history of a map tile within their limited internal storage space. Thus they have to provide the whole map tile of a layer of the HD-Map to their neighbours. Depending on the covered area, such a map tile can be a small number of megabytes in size [1]. The ad hoc communication realized by the 802.11p standard[32], however, has been specifically designed for small amounts of data (several hundreds of bytes) to be transmitted at once. Thus we propose to split up a single map tile into smaller chunks of data, which are then transmitted individually, to ensure a reliable data reception. Depending on the time, in which the cars are in range to each other, they can share several of those data chunks up to several complete map tiles.

Only if the requesting car does not receive all the required data chunks of a map tile via ad hoc transmission until it reaches a certain minimum distance to the requested map tile, it will then request the remaining data parts directly from the map server through the cellular network (2.b)). This update will than be added as well to the internal map storage of the car as it is relevant for its current trip and thus can be provided further to other vehicles in the surrounding. For example, this is the case for the cabriolet, as its outdated map tile could not be provided by the sedan. We consider the cellular communication as a fall back option in HD-Wmap, that is available, but comes at the price of high transmission costs, respectively lower efficiency.

To investigate the performance of the HD-Wmap extension we present the first obtained results from a simulation of the city area of Cologne in the following Evaluation Section 5.

5 EVALUATION

There are several parameters, which are influencing the performance of HD-Wmap. This includes the available throughput bandwidth of the current ad hoc connection to transmit data. Furthermore, the size of the home zone of each vehicle influences HD-Wmap. A larger home zone increases the probability to share map

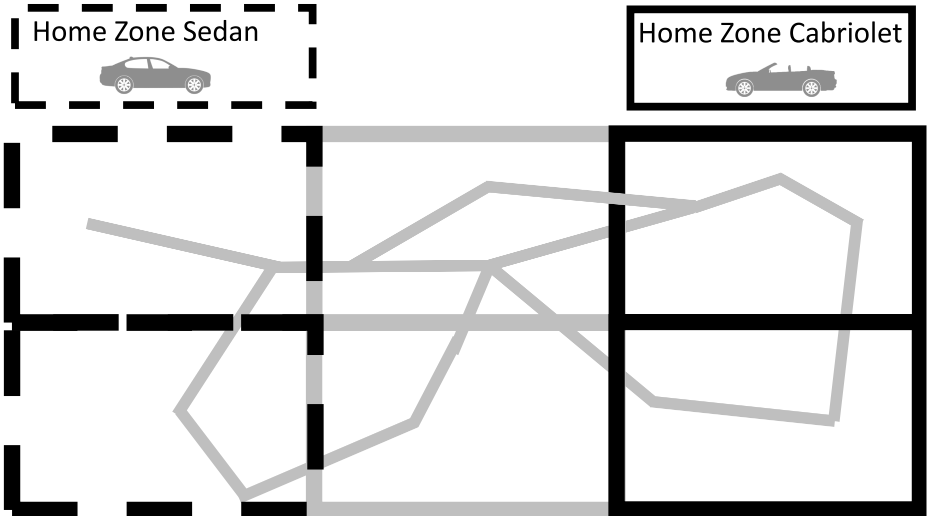

Fig. 3. Example for two different home zones of two cars.

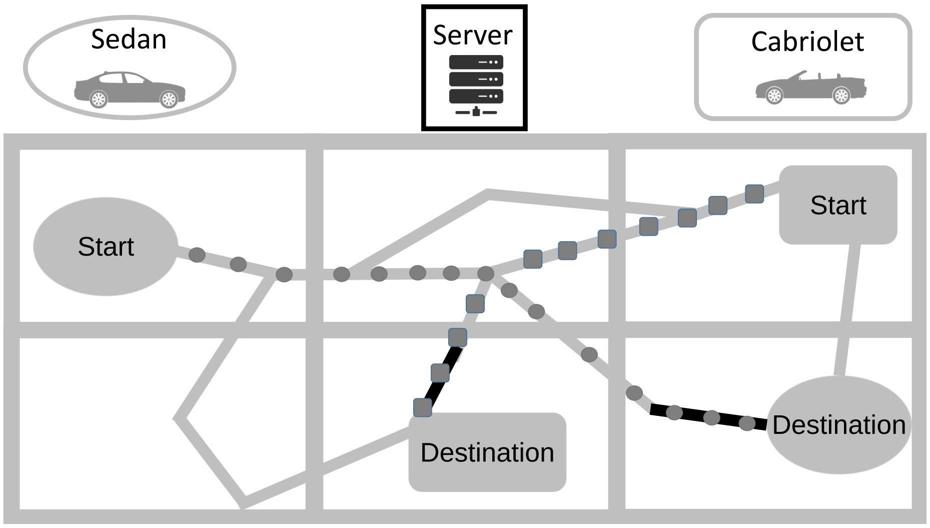

Fig. 4. Example scenario for HD-Wmap to illustrate the ad hoc sharing of map data.

material with others. The size however should be kept as small as possible to leave enough space for other map material in the limited storage space of the vehicles. Also the transmission range of the vehicles by which they are able to transmit data to each other has to be considered. The different configurations of the aforementioned parameters are now analyzed in the following.

5.1 TAPASCologne Scenario

For the evaluation of HD-Wmap we relied on a traffic scenario, which was created based on the area of the city of Cologne. We based our simulation on map material available by the OpenStreetMap[8] project, as to the best of our knowledge, there is currently no high definition map material public for testing the protocol. TAPASCologne[9] is a simulation scenario for the traffic simulator SUMO[10] resembling the daily traffic in the area of the city of Cologne in Germany. A dataset for the morning rush hour between six and eight o'clock is public available. We extracted the corresponding street map states for each day of August 2016 as a lower bound estimation for changes in future HD-Maps. Each of the three scenarios presented in the following has been conducted 30 times, based upon 30 different states of outdated map data. These difference files have been created by comparing the map data of the first day of August to the data of the remaining 30 days. With the help of SUMO we extracted the trip of each of the roaming cars with a timely resolution of 10 seconds. As in our previous work [21] we assumed a grid size of 5km x 5km (resembling a Geohash of size 5) for all map tiles present within the simulated area of Cologne.

5.2 Scenario Configuration

As the provided city scenario of Cologne is still rather small with a coverage area of about 40km x 40km with respect to a map tile size of 5km x 5km, we configured the vehicles in our simulation to immediatly request their required map tiles. Therefore, we assumed a circular transmission range of messages of 300 meters [26], [45] for the 802.11p technology [32] to be commonly achievable. The home zone area of each vehicle was simulated for two different sizes. The home zone size zero only includes the map tile from which each vehicle starts. A home zone of size one adds the eight surrounding map tiles to the list of stored data. We use a simplified transmission model, which is independent from technology and allows the

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[8] https://www.openstreetmap.org/

[9] http://sumo.dlr.de/wiki/Data/Scenarios/TAPASCologne

[10] http://sumo.dlr.de/

evaluation of different transfer rates and map sizes. In this model, a partial transmission of one data chunk is finished each time step. Thus, the transfer rate and the map size can be modeled with a varying number of chunks to be transfered. A car can share map tile layers as soon as their download is finished. Chunks that could not be received via ad hoc communication in time are downloaded instantly via a cellular connection. This is a simplification regarding the simulation accuracy that will be extended in future work. With an area of about 5km x 5km covered by a map tile of Geohash size five, we assumed a data size of the tile of about 10 megabytes [1]. In our opinion this is expected to be an average reasonable size of a map tile covering city streets. Due to the different kinds of street networks, this value, however, might change depending on the exact represented location in a real implementation of HD-Wmap. To transmit such a map tile for example with a slow transmission speed of only 0.5 Mbit/s would require 160 seconds. In our simulation this time is mapped onto the transmission of 16 consecutive data chunks due to the time progress of 10 seconds per simulation step. To ensure a transmission at even worse network connectivity conditions we investigated values of data chunks required for a full map tile as illustrated by Figure 5. To cover different scenarios, we vary the number of chunks from 1 to 70 in our evaluation.

5.3 Percentage of offloaded map data

As the first evaluation metric we analyze the percentage of map tiles, which can be received via ad hoc communication in comparison to the remaining amount of data that has to be transmitted via the cellular network. The achieved savings are presented in Figure 5. The investigated range reaches from only one necessary data chunk representing a data connection with a high bandwidth of 8 Mbit/s by assuming a map tile size of 10 megabytes, up to 70 resembling a very poor data connection of only 114 Kbit/s. In this the further parameters were fixed as a home zone size of zero with a transmission range of 300 meters.

HD-Wmap thereby achieved a sharing quota of up to 25.5% in average under the best transmission conditions. It clearly shows the effectiveness of the approach to off load the transmission of map data from the cellular network via ad hoc communication. This quota only decreases by 1/3 to around 17.8% when the ad hoc channel capacity is reduced to 1/70 of its initial value. This indicates, that the offloading is limited by other factors besides throughput that require further investigation in the future.

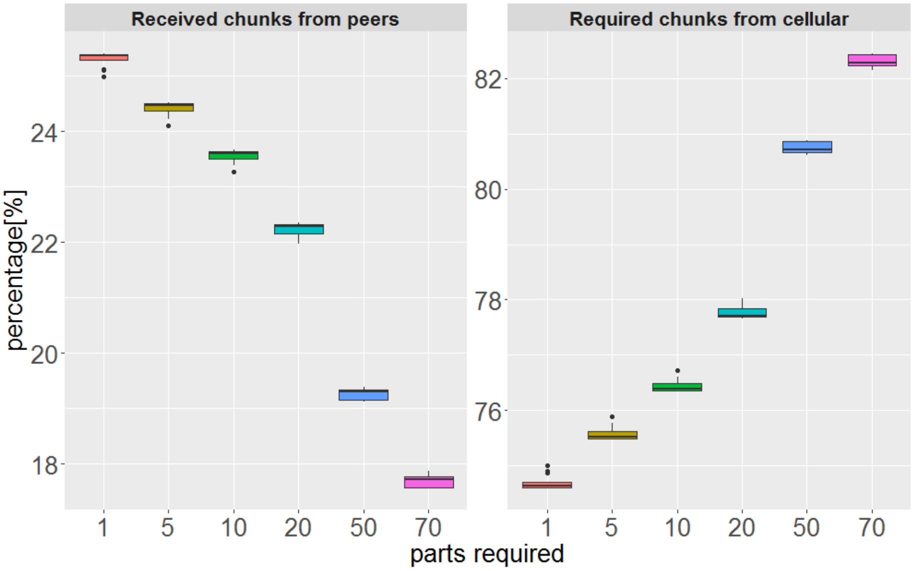

Fig. 5. Investigation of different amounts of data chunks to be required per map tile.

5.4 Variation of the transmission range

The second parameter of the simulation, that we investigated is the transmission range of the vehicles as shown by Figure 6. Initially set to a distance of 300 meters we further reduced this value to 200, 100 and 50 meters. The amount of required data chunks was set to 20 and the home zone size to 0.

In comparison the reduction of the transmission range to 1/3 or 1/7 of the initial value only led to a reduction of the sharing functionality by 7.2% respectively 18.4%. This reflects the simulated scenario of Cologne in the morning rush hour with a probably high portion of commuting trips in the amount of all performed trips. Commuting trips mostly follow common main roads and lead to congestion due to a high density of vehicles, which allows efficient sharing of map data even with a largely reduced transmission range.

5.5 Variation of the home zone size

The third and final parameter, which we varied in our evaluation is the size of the home zone. Furthermore a transmission range of 300 meters and a required amount of 20 data chunks was fixed. As stated previously a home zone of size zero only includes the map tile that covers the start position of the vehicle. A home zone size of one adds the eight surrounding map tiles to it. As expected, the amount

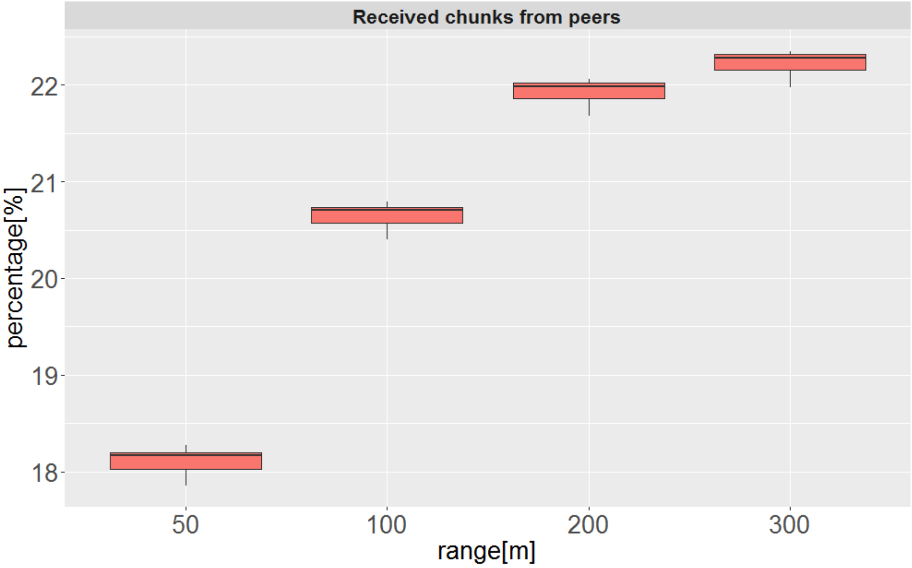

Fig. 6. Comparison of different transmission ranges.

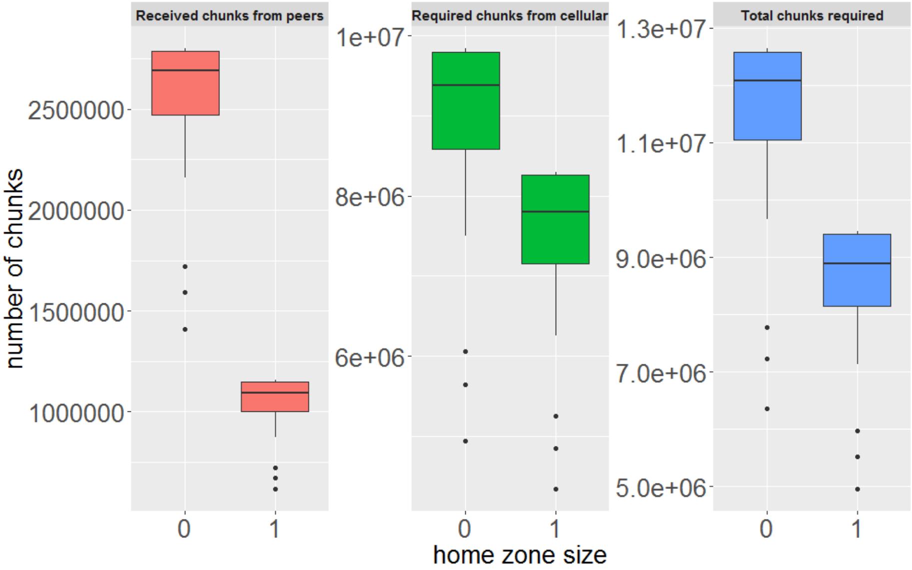

Fig. 7. Comparison of different home zone sizes in absolute numbers.

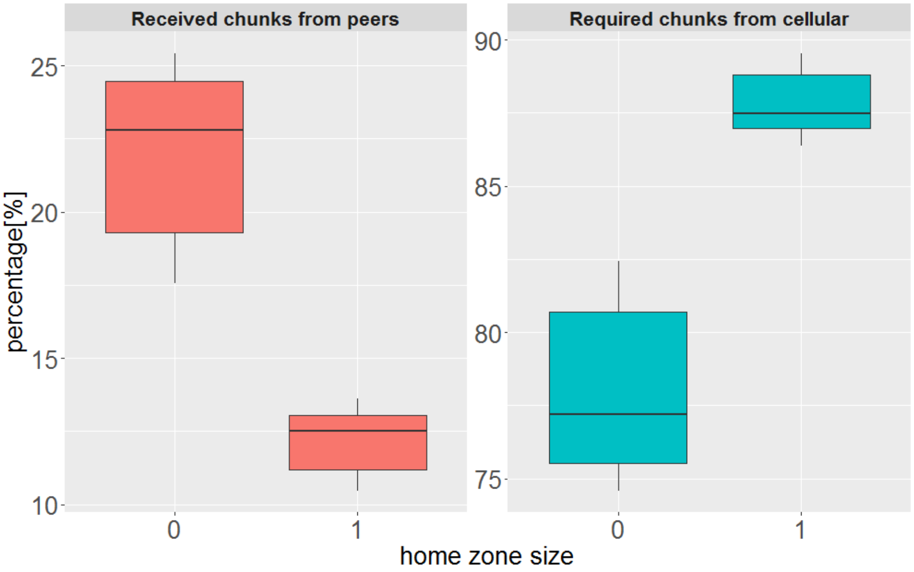

Fig. 8. Comparison of different home zone sizes in percentage.

of total required chunks to perform a car's trip can be reduced significantly by increasing its home zone size as indicated by the rightmost graph in Figure 7. Interestingly, the amount of chunks which could be shared via ad hoc communication also decreases with an increased home zone size (see leftmost graph in Figure 7 and the graphs of Figure 8). This is presumably due to a high percentage of short trips to be simulated in the morning commuting scenario. A larger home zone of size one leads to the situation that cars, which only perform trips, with a range between 5 and 10 kilometers do not have to request any more map tiles, as it would have been the case for a home zone size of zero. The smaller amount of vehicles, which perform larger trips in the small Cologne scenario to the outskirts of the map, however, might not find a suitable exchange partner due to a decreased density of cars in these areas. Finally this leads to an increased percentage of necessary cellular transmission for all considered trips, which require updates to their database. We expect a larger scenario with longer travel distances or a smaller map tile size and a more homogeneous distribution of vehicles to show higher offloading potential.

6 CONCLUSIONS AND FUTURE WORK

This paper presents HD-Wmap, an extension of the Dynamic Map Update Protocol [21]. The Dynamic Map Update Protocol has been designed to enable efficient context based map data updates, which are required for Advanced Driver Assistance Systems and highly automated vehicles. Our proposed extension HD-Wmap improves the achieved results further by introducing the capability to the cars to share personal map data with the vehicles in their proximity. This is achieved by relying on ad hoc communication technology in the vehicular context, like the 802.11p standard [32]. To the best of our knowledge, we are the first work to propose a concrete concept to share map data between vehicles via this technology. To ensure the fair and efficient data sharing between the vehicles we propose the concept of a so called home zone in which the vehicles roam the most. This area is assumed to be updated and stored prioritised in the car's internal storage space. Vehicles preferably request map updates via ad hoc from surrounding ones and use the cellular updates from our previous work as backup procedure.

Within the simulated scenario of Cologne, HD-Wmap achieved an ad hoc map data off loading quota of up to 25.5%. Especially the design and the selection of a proper home zone area for each vehicle denote very important factors to improve the ad hoc data sharing-efficiency of the map updating process.

We plan to extend our initial home zone concept. For example, daily commuting trips of the vehicles should be considered to be included in the home zone as well to improve their sharing capabilities through HD-Wmap. Future simulations will span larger areas to reveal the complete efficiency improvement of the offloading strategy of HD-Wmap, which we expect to be even higher.

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