Efficient Uplink from Vehicular Micro Cloud Solutions to Data Centers

Gurjashan Singh Pannu*, Takamasa Higuchi†, Onur Altintas† and Falko Dressler*
*Heinz Nixdorf Institute and Dept. of Computer Science, Paderborn University, Germany
†Toyota InfoTechnology Center, Tokyo, Japan and Toyota InfoTechnology Center, Mountain View, CA
{pannu,dressler}@ccs-labs.org, ta-higuchi@jp.toyota-itc.com, onur@us.toyota-itc.com

***Abstract*—One of the most recent applications in the vehicular networking domain is distributed data processing using cars as sensors of information. In recent work, the concept of vehicular cloud computing has been explored to provide the necessary scalability and to improve the communication between clusters of cars being called vehicular micro clouds and other participants (cars, bicyclists, pedestrians). In order to provide a bigger picture and also to interconnect such micro clouds, data centers or cloud servers are considered bridging the gap. We study the uplink capabilities from connected cars to such data centers. Options include direct LTE uplinks from all cars, selected use of Roadside Units (RSUs) with back-end connectivity or LTE uplinks from the vehicular micro clouds, and finally hybrid solutions taking network quality and available channel resources into account. Our findings clearly show the advantages of such hybrid solutions both in terms of throughput as well as of optimizing operational costs.**

I. Introduction

With the beginning deployment of vehicular networking technologies, research focuses now on applications beyond so-called day-one applications in the road safety sector. For example, when using cars as distributed sensor, very relevant information can be collected without the need to install similar sensors in the environments. This includes so-called Floating Car Data (FCD) helping to shed light into traffic congestions including micro jams but also envisions future applications of Intelligent Transportation Systems (ITS) like the exchange of real-time images and others. In order to maintain such data and make it available to other cars, either infrastructure could be deployed (e.g., Roadside Units (RSUs) have been installed on larger scale in major Japanese cities) or we could rely on the cars themselves spanning (fragmented) networks on the roads.

From a communications technology point of view, a number of alternatives have been developed in the last decade and even more are currently investigated including Dedicated Short Range Communication (DSRC), often labeled IEEE 802.11p, LTE and LTE-D2D, and many others including Line-of-Sight technologies like Visible Light Communication or mmWave based communication. To improve scalability, heterogeneous approaches are often considered as candidate solutions [1].

In the context of distributed data management among cars, several proposals have been published, most notably the concept of a vehicular cloud [2]–[4]. Many of these works converged later into what has been called the hierarchical vehicular cloud computing architecture [5] (Fig. 1). The core idea is to use cars as sensors as well as entities which are able to process, store, and transfer data [6]. In this architecture, cars dynamically group to clusters that collaboratively join the process as a virtual edge server, the vehicular micro cloud. This vehicular micro cloud, in turn, supports all the processing and storage activities required in a local geographical context, in particular supporting the offloading process from cars to a data center.

In this context, quite some work has been done on the download part. This, for example, includes the optimization of access point selection for downloading data from the cloud (here, data centers) [7] and also considering the support of multi-hop vehicular networking in a heterogeneous environment to speed up the process and to make it more reliable [8]. Studies also revealed some insights on the impact of partial information when it comes to road traffic optimizations [9].

We concentrate on the uploading process from cars to the data center. Relevant communication technologies, again, include DSRC, Wi-Fi, and LTE networks [10]. By merging this with the concept of the vehicular micro cloud, we are now able to make better use of the available communication resources. In this paper, we discuss the migration path from the baseline using simply LTE uplinks from every car to naïve solutions where the vehicular micro cloud picks the next available RSU or just a LTE modem of one of the cars in the cluster to more advanced solutions taking available network resources and the load in the wireless network into account. We study the performance-cost trade-off and show the advantages of using hybrid solutions dynamically selecting the best suited RSU to which the micro cloud is connected as well as LTE-equipped cars in the cluster with the best LTE connection.

Our contributions can be summarized as follows:

- We present a novel concept for making the uploading process from the vehicular micro cloud to a back-end data center more efficient and cost effective (Section III). Our concept adaptively picks the best suited RSU or an available LTE modem from within the cluster depending on network load and available resources.
- In a detailed performance study, we outline the advantages of our concept by comparing it to a baseline scenario as well as to naïve solutions where the vehicular micro cloud picks the next available RSU or just a LTE modem of one of the cars in the cluster (Section IV).

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II. Related Work

The vehicular micro cloud concept has been proposed by Higuchi et al. [5]. The core idea is to establish an architecture similar to and extending the Mobile Edge Computing (MEC) concept. Conceptually, this architecture builds upon earlier works on the vehicular cloud [2]–[4]. The idea is to cluster cars on the road into groups that provide a rather stable internal network topology. Cars in the cluster – now called the vehicular micro cloud – can now start interacting to provide storage, processing, and message relaying capabilities to other cars and even to other road users including pedestrians and bicyclists. The concepts of sharing storage and processing capabilities have been primarily developed in the scope of Car4ICT, a project aiming at making cars a main ICT resource in future smart cities [6]. The vehicular micro clouds are connected to each other and to a back-end data center via RSUs or cellular networks such as LTE. In the core network, physical edge servers may support the network by means of caching. That way, the vehicular micro clouds can also be regarded as virtual edge servers. The full vehicular micro cloud architecture is depicted in Fig. 1.

As we are interested in the data uploading part, we also have to explore more general concepts of FCD offloading. One of the first works including a problem formulation has been presented by Stanica et al. [11]. The core idea of early works was to use LTE uplinks for the uploading process [12]. This was later also supported by heterogeneous networking solutions using in part Wi-Fi, DSRC, and LTE [8], [10]. Most notably, the need for integrating DSRC with Wi-Fi Access Points (APs) and LTE uplinks was demonstrated allowing to bridge communication gaps between APs and to reduce the cost for permanent LTE uplinks. Looking at the decision criteria for when to pick LTE or a short-range communication technology, several works looked into identifying channel properties as a tie breaker [13]. Most recently, the Channel Quality Indicator (CQI) has been explored as a direct estimate for the LTE uplink performance [14].

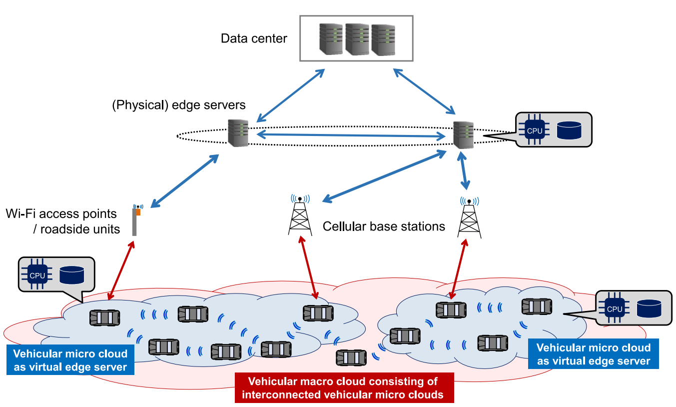

Fig. 1. Vehicular micro cloud architecture [5]. Cars on the road form clusters that are used to locally store and process received data. Micro clouds can be seen as virtual edge servers in the architecture interconnected by physical edge servers and back-end data centers.

The next step is to set up and to maintain the vehicular micro clouds using clustering concepts. Clustering algorithms can be categorized in multiple ways, e.g., based on scenario or based on coordination. The dominant scenario is a freeway where clustering algorithms are able to exploit the predictable movement patterns of driving cars [15], [16]. For clustering algorithms in urban scenarios, movement patterns become less predictable [17]. These clustering algorithms try to solve this most of the time by supporting the clustering process with an RSU. Regarding coordination, the usual focus of clustering algorithms is on completely distributed algorithms [15], [18]. Still, certain proposed algorithms rely on a centralized coordinator node [17], [19]. As distributed algorithms in urban scenarios induce a larger overhead for achieving stable clusters, we also rely on a centralized coordinator node, e.g., an RSU or a cellular base station. Bringing parked cars into the picture helps substantially to maintain very stable clusters. The use of parked cars as information relays has been in-depth explored in the literature [8], [20], [21]. In earlier work, we focused on the use of clusters of parked cars for information management [22]. The baseline is to provide algorithms integrating routing and information management ideas such as the Virtual Coord Protocol (VCP) protocol [23]. VCP establishes a Distributed Hash Table (DHT) in the local network that helps storing and retrieving data very efficiently.

III. Upload Concept from Vehicular Micro Cloud to Back-End Data Center

The vehicular micro cloud can support wide range of services requiring computational and storage resources. In this paper, we focus mainly on the storage and relaying capabilities of such a virtual edge server. As a prime example, we study collecting data from the driving cars and uploading it to the data center. This is a common, yet very important application for the efficiency of future ITS. The data generated by the driving cars mainly consists of awareness information, e.g., the car's geographic location, speed, direction, time, etc. It can further include one-hop or two-hop neighbor information (e.g., for efficient multi-hop broadcasting [24]) and other data about ongoing events or incidents along the road, e.g., construction areas, accidents, traffic jams, etc. With the increasing number of sensors being connected to the cars, we can only expect the data generation rate to increase. There are multiple possible options to upload the data from the cars to a back-end data center.

A. Baseline Approach

Assuming that all cars have an LTE modem and there is connectivity, the baseline option is that each car selects a timeout T_o after which it periodically uploads the generated data via the LTE uplink directly to the data center. This approach has several drawbacks. First and foremost, there will be a very high resource block utilization in the LTE uplink, which is directly proportional to the resulting costs. Secondly, good

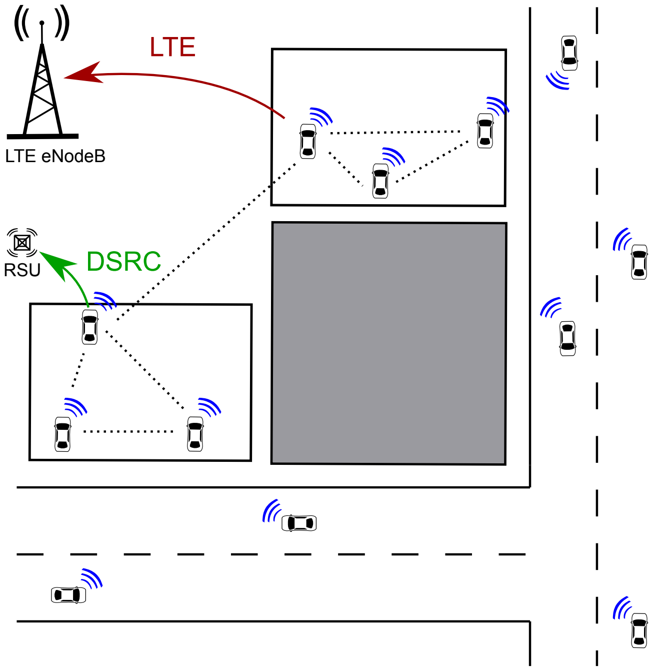

Fig. 2. A vehicular micro cloud in action. It collects data from the driving cars, aggregates it, and later uploads it to a back-end data center via multiple available network technologies (DSRC, LTE, hybrid).

network coverage is required, which hold for most major cities but is unrealistic for smaller places.

B. Vehicular Micro Cloud Approach

With the help of the hierarchical vehicular cloud computing architecture, we believe that this can be changed to a win-win situation. In this case, (parked) cars form clusters named vehicular micro clouds and starts offering data collection service to the driving cars. The offers are minimal broadcast messages sent periodically as described by Altintas et al. [6]. In this study, we refer to these broadcasts as *Data Collection Service Offers*. When the driving cars receive this offer, they can connect to the vehicular micro cloud and start uploading data. Later, this data can be aggregated and uploaded by the micro cloud to the data center. Fig. 2 shows the high-level overview of the concept. As can be seen, parked cars establish clusters and help finding possible RSUs or LTE base stations for relaying the messages in order to upload the data to a data center.

We believe that the benefits of this approach are multifold. First, the driving cars are no longer required to individually upload the data via LTE uplink. Second, they can rely upon technologies which are essentially available free of charge, e.g., RSUs to which the cluster can provide a stable network connection. The third benefit lies in the flexibility of the vehicular micro clouds. The flexibility can be in terms of available uploading technologies like RSUs nearby the parking lot or LTE uplinks. Fourth, the micro cloud also contributes in aggregation of the data collected from several driving cars before uploading it to the data center. An efficient aggregation technique can improve the network performance significantly. Finally, since a micro cloud is pretty stable in time domain, it gives an opportunity to analyse the existing channel conditions and make intelligent decisions in the gateway selection for the uploading process. This is beyond the capabilities of the moving cars.

C. Gateway Selection in the Vehicular Micro Cloud

The data uploading process from driving cars to the data center can be divided into two steps:

- from a driving car to the vehicular micro cloud and
- from the vehicular micro cloud to the data center

For both of these steps, the micro cloud needs to select gateways. In the first step, gateway selection has been explored in earlier work already [22]. Driving cars send the data to the car from which they received the last *Data Collection Service Offer*. Since the micro cloud relies upon a DHT based VCP [23], the data received by any gateway will be forwarded to a deterministic member in the micro cloud.

However, several research questions arise in the second step:

- Which car should be selected as a gateway to upload the data from the vehicular micro cloud to the data center?
- Shall there be only one such gateway or multiple gateways uploading data in parallel? Multiple gateways can help in delivering better uploading rates, but if used on the same channel, the upload procedure can also interfere and downgrade the performance.
- Which network technologies should be preferred and shall there be a hybrid multi-technology approach?

In order to address these questions, we study the following three different concepts:

One randomly selected DSRC gateway: This scenario is based upon an assumption that there is a RSU available in communication range of the vehicular micro cloud and none of the participating cars has LTE capabilities (or denies its use due to related monetary costs). One of the cars in the micro cloud is then selected as a gateway at random and uploads the data to the data center.

One randomly selected LTE gateway: This scenario is based upon the assumption opposite to the previous one, i.e., there is no RSU available. However, all the cars (or at least one) in the vehicular micro cloud have LTE connectivity. So, any one of the members is selected as gateway at random and is responsible for uploading the data to the data center.

Hybrid DSRC and LTE gateway selection: Random gateway selection does not guarantee good performance. Thus, in this configuration, the vehicular micro cloud takes measurements such as the channel conditions into the consideration. We assume that there is a RSU nearby the parking lot and the cars also have LTE connectivity. Details on the selection algorithm are explained in the following.

D. Hybrid Approach

All the cars participating in the vehicular micro cloud continuously measure the quality of the channel, ρ, as experienced by them. For the DSRC channel, the channel quality ρ_{DSRC}

is measured in terms of the channel busy ratio, the signal-to-interference-plus-noise ratio (SINR), and the distance between the parked car and the RSU. This is in line with, for example, the congestion control mechanism in the ETSI ITS-G5 vehicular communication standard [25].

The RSU sends periodic beacons including its location [26]. Given that the parked cars are also equipped with GPS modules, each of them knows the distance between the RSU and itself. We consider the distance as one of the factors for influencing the DSRC channel quality. In addition to it, we also consider the channel busy ratio and the SINR as observed by the cars.

The channel busy ratio indicates the fraction of time for which the wireless channel was sensed busy. The rule of thumb is, the higher the channel busy ratio, the worse is the channel quality. The busy time ratio is given as

$$b_t = \frac{t_{\text{busy}}}{t_{\text{busy}} + t_{\text{idle}}} \; , \tag{1}$$

where t_{busy} denotes the channel busy time and t_{idle} is channel idle time since the last measurement. The ETSI ITS-G5 standard also mandates the transmission of the observed channel busy ratio in the so-called geonetworking header [27]. The information about the channel conditions at the RSU can be estimated accordingly.

The SINR is defined as the ratio of received signal strength to the signal strength received from other sources as well as thermal noise.

$$\text{SINR} = \frac{P_{rx}}{\sum P_i + N} \; , \tag{2}$$

where P_{rx} is the received signal power, $\sum P_i$ represents the power received from other sources as interference, and N represents white Gaussian noise. The higher the SINR, the better is the channel quality.

We now calculate the overall DSRC channel quality as

$$\rho_{\text{DSRC}} = \frac{\text{SINR}_{\text{DSRC}}}{b_t \times d} \times \omega \tag{3}$$

where d is the measured distance between the RSU and the car and ω a scaling factor for optimizing the resulting threshold. We configured the model for the simulation experiments empirically; a full parameter study is left to future work.

In the LTE uplink, the base station (eNodeB) measures the CQI as an uplink channel quality metric for the user equipment. It can again be based upon the SINR as observed at the eNodeB. We assume that the CQI of LTE uplink is available to the vehicular micro cloud by way of car modems. We use it as a metric to estimate the channel quality ρ_{LTE} between the cars and the eNodeB. For simplicity, we define

$$\rho_{\text{LTE}} = \text{CQI} \; . \tag{4}$$

Based upon the defined channel quality metrics, the DSRC gateway can be selected as

$$\mathbb{G}_{\text{DSRC}} \leftarrow \operatorname*{argmax}_{n \in \mathbb{N}} \rho_{\text{DSRC}_n} \tag{5}$$

and the gateway for LTE can be calculated as

$$\mathbb{G}_{\text{LTE}} \leftarrow \operatorname*{argmax}_{n \in \mathbb{N}} \rho_{\text{LTE}_n} \tag{6}$$

Furthermore, both gateways can be used together to upload the data in parallel. Since both of them use the different technologies to upload the data, they contribute to the better performance of the network.

IV. Performance Evaluation

A. Simulation Scenario and Setup

In order to evaluate the performance of the designed algorithms, we used the Veins LTE vehicular network simulation toolkit [28]. The simulation scenario is based upon a subset of the Luxembourg city scenario [29], which offers real road patterns, building locations and traffic mobility. For comparability, we picked the same region of interest as in [22].

A high level view of the scenario can be seen in Fig. 3. It consists of two parking lots at a T-junction separated by a building in the middle. The parked cars from the two parking lots form a single vehicular micro cloud using VCP [23]. This gives the driving cars an opportunity of elongated connection times via DSRC to upload the FCD. Although, the vehicular micro cloud can also aggregate the collected data before uploading it to the data center, for simplicity, we did not include the aggregation step in the simulations. This means that the size of data to be uploaded to the data center is same as the size of data collected from the driving cars. The simulated time is part of the morning traffic rush hour.

In all experiments, we varied the message size from 1 kB to 16 kB to gain insights into the behavior for different loads and message sizes. All driving cars generate messages every 2 s and transmit this data to the data center (either directly or via the vehicular micro cloud). Detailed simulation parameters can be found in Table I. All simulations have been repeated at least 35 times. We checked all confidence intervals and were able to confirm that we obtained statistically significant results where the mean value is a true representative. All the plots show the mean value together with the 5 % and 95 % quantiles.

TABLE I
Simulation Parameters.

Parameter	Value
Short rang communication technology	DSRC (no retransmissions)
Channel	5.89 GHz
Transmission power	20 mW
Bandwidth	10 MHz
Data rate	6 Mbit/s
Cellular technology	LTE
Number of available RBs (UL & DL)	15
LTE scheduler	MAXCI
UE transmission power	26 dBm
eNodeB transmission power	45 dBm
Average number of driving cars	30
Other LTE users	15
Background LTE traffic	4 kB + uniform(−2 kB, 2 kB)
Background LTE traffic interval	1 s + uniform(−0.5 s, 0.5 s)
Parked cars in two parking lots	10 and 9
Simulation duration	200 s
Repetitions	35
Data generation interval	2 s
Data size generated	1, 2, 4, 8, 16 kB

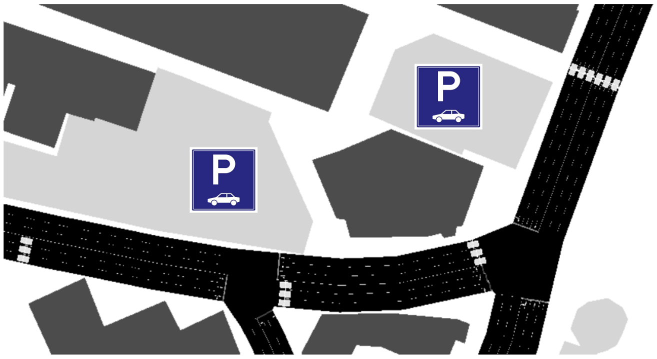

Fig. 3. Overview of the simulation scenario. The street map is part of the city of Luxembourg. In addition to the streets, two major parking places are indicated, which have a direct line of sight connection, i.e., cars parking represent one connected vehicular micro cloud.

In the simulation experiments, we investigated four different configuration options:

- *Baseline:* All the driving cars upload the FCD directly to the data center via LTE.
- *DSRC:* Driving cars transfer the FCD to the vehicular micro cloud via DSRC and it is uploaded to the data center via a randomly selected DSRC gateway.
- *LTE:* FCD is transferred to vehicular micro cloud via DSRC, but the gateway used by the micro cloud is a randomly selected LTE gateway.
- *Hybrid:* Vehicular micro cloud selects the best suited gateways based on ρ_{DSRC} and ρ_{LTE}. Both the gateways upload the data to the data center.

B. LTE Resource Block Utilization

In the LTE uplink, we look into the resource block utilization, i.e., the fraction of the total resource blocks that have been allocated to the cars for uploading. As shown in Fig. 4, we can see that the resource block utilization increases with the increasing data size in the baseline scenario. This is because more resource blocks are required as the amount of data to upload increases. In contrast, both Hybrid and LTE gateway selection algorithms have a similar resource block utilization and it remains constant throughout. This is because both the algorithms select only one parked car as a gateway for uploading via LTE. As a result, it does not impose any pressures on the LTE network. We do not see any line for the DSRC configuration, because the LTE uplink is not used in it at all.

C. DSRC Channel Utilization

It is to be expected that, with increasing the data size, the DSRC channel utilization increases as more data needs to be transmitted. The plot in Fig. 5 confirms this assumption. In the DSRC gateway selection algorithm, the channel saturates much earlier compared to the others as both types of data transfer (data collection from the driving cars and data uploading to the data center) use the same channel. LTE and Hybrid gateway selection algorithms have comparable channel utilizations.

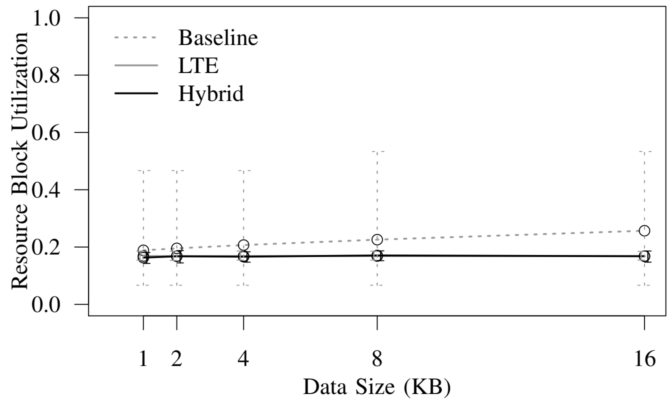

Fig. 4. Resource block utilization.

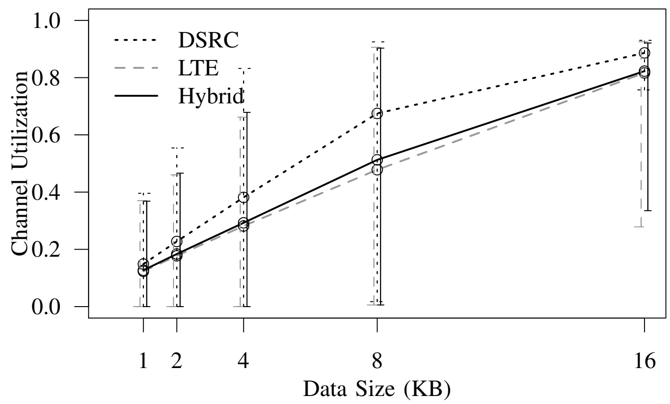

Fig. 5. Channel utilization.

Hybrid gateway selection algorithm consumes a little more than the LTE gateway selection as LTE configuration does not use DSRC channel for uploading at all. We do not see any line for the baseline as it uses only the LTE uplink.

From Fig. 4 and 5, we can conclude that relying upon a single technology can result in undesirable exploitation of the network resources. This shows the need for hybrid approaches to upload the data from the vehicular micro cloud.

D. Data Uploaded over Time

We further measured the amount of data uploaded to the data center. The results are plotted in Fig. 6. The baseline shows the best performance with nearly all the data being uploaded, however, this comes at the cost of pure LTE usage. In other words, the users pay for the allocated resource blocks. When only the LTE or DSRC gateway is used, the performance is not so good. It can be argued that there is only one gateway, which has become a bottleneck in the uploading process. When both LTE and DSRC gateways operate together, we see a significant increase in the amount of data transferred. It seems to be a middle ground between the cost and efficiency.

E. Success rate

Fig. 7 shows the success rate of the data transfer. We can see that in the baseline experiment, all the data was successfully

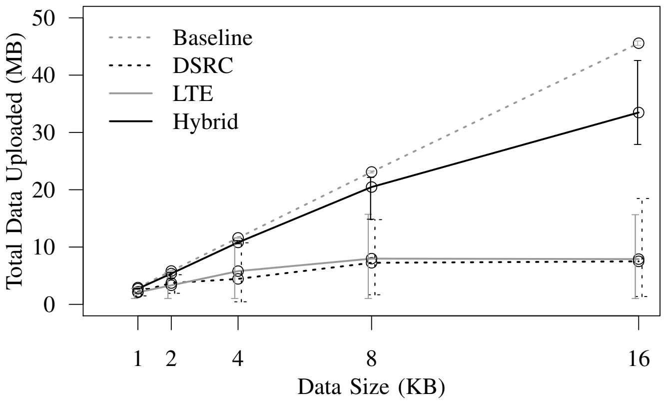

Fig. 6. Total data uploaded to the data center.

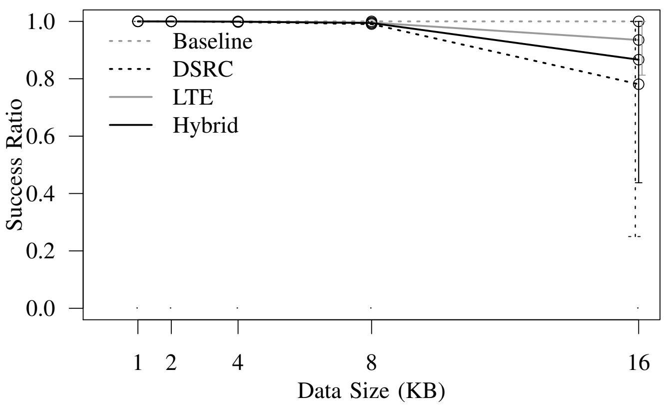

Fig. 7. Success ratio of uploaded data.

uploaded to the server. In the other configurations, for smaller data sizes where channel utilization is low, all approaches have close to 100 % success rate. Looking at the 16 kB messages, however, we see a slight performance degradation. Using the LTE gateway, we see the success rate of around 91 %. The hybrid gateway selection shows around 85 % and the worst is for pure DSRC based gateway selection (77 %). This outcome is also backed by the observed channel utilization in Fig. 5. With no retransmissions used in data transfer over DSRC channels, some transmissions are bound to fail.

These results can be further confirmed when looking at the per message success rate of transmitted fragments. As every message of 1 kB to 16 kB needs to be fragmented when transmitting via DSRC to the vehicular micro cloud, it is not only interesting how many complete messages have been received but particularly how many fragments per message have been received. This information is plotted in form of histograms in Fig. 8. As can be seen, there is a non-negligible probability that multiple but not all fragments are received per message. This behavior can be exploited in future work by adding network coding concepts to improve the overall communication reliability. The plots also reveal, again, the advantages of the hybrid solution. Overall, the hybrid concept clearly outperforms the more naïve RSU and LTE base station approach.

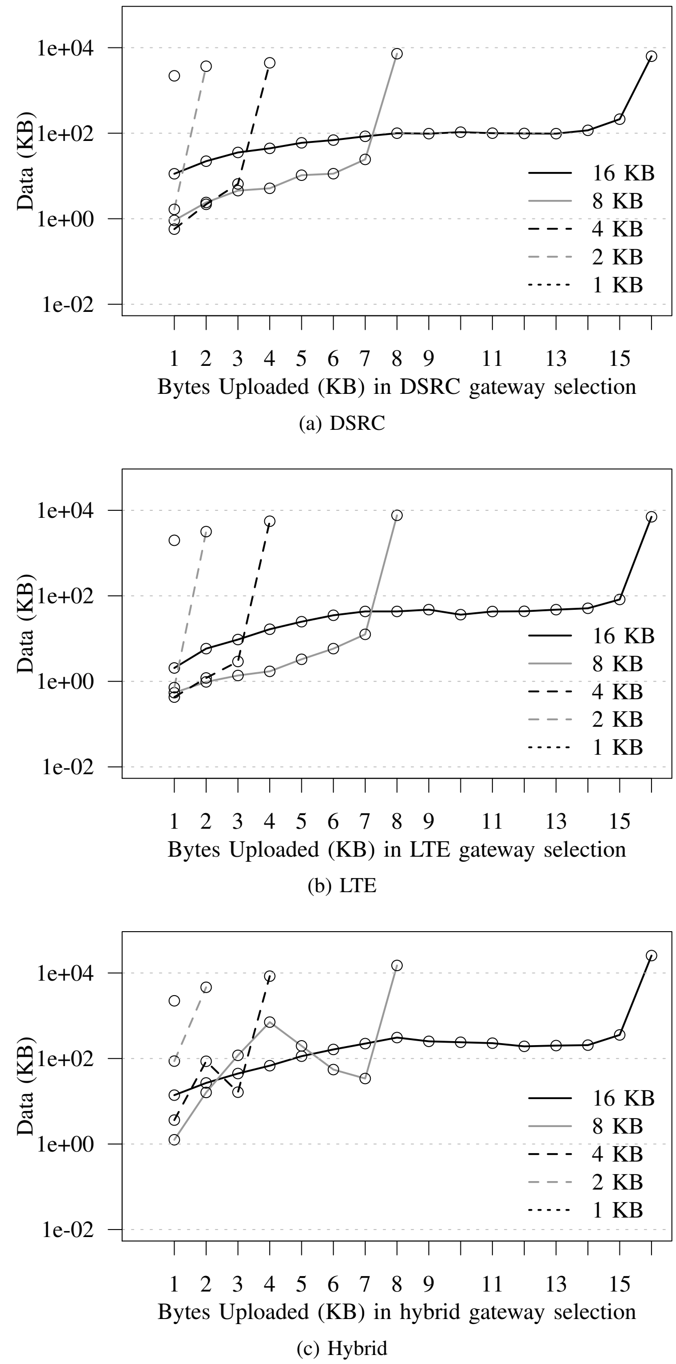

Fig. 8. Histogram of success ratio of uploaded data per message.

V. Conclusion and Future work

In this paper, we investigated the uplink capabilities from cars via a vehicular micro cloud to a back-end data center. As found out, this problem can be reduced to the gateway selection problem for uploading the data. Besides a baseline measurement, we explored three different configuration options: First, using a Roadside Unit (RSU) with back-end connectivity to which the micro cloud is connected for all uplink data. Secondly, using a dedicated LTE modem (of one of the cars being part of the vehicular micro cloud) for the uplink. Finally, we designed a novel approach to adaptively select a gateway to a RSU as well as an LTE gateway based upon measured channel conditions. Both gateways rely upon different technologies and, if used together, help substantially in improving the uploading performance from the vehicular micro cloud. More specifically, our approach is scalable as the resource block utilization did not change with increasing data size. We also identified data losses over the DSRC channel, which becomes clear when looking at the channel busy ratio – the channel becomes saturated. As future work, we plan looking into advanced techniques like network coding, which can help in making the uplink channel even more reliable.

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