Vehicular Virtual Edge Computing using Heterogeneous V2V and V2C Communication

Gurjashan Singh Pannu*, Seyhan Ucar†, Takamasa Higuchi†, Onur Altintas† and Falko Dressler*

*School of Electrical Engineering and Computer Science, TU Berlin, Germany

†InfoTech Labs, Toyota Motor North America R&D, CA, U.S.A.

{pannu, dressler}@ccs-labs.org,

{takamasa.higuchi, seyhan.ucar, onur.altintas}@toyota.com

***Abstract*—Recently, much progress has been achieved virtualizing edge computing and integrating end systems like modern vehicles as both edge servers as well as users. Previously, it was assumed that all participating vehicles share the same vehicle-to-vehicle (V2V) communication technology to exchange data. Uplinks and downlinks to the cloud or a back end data center are provided by gateway nodes that also have a vehicle-to-cloud (V2C) communication interface. We now go beyond this initial architecture and consider quite heterogeneous communication technologies deployed at each vehicle. In particular, we assume that each vehicle is equipped with either V2V or V2C communication, or both so that it can also act as a gateway between the different worlds. We call the resulting system hybrid micro clouds. In this paper, we present means for hybrid micro cloud formation such that every vehicle can exchange data with other vehicles as well as with the back end data center. In our performance evaluation, we looked at the position error of neighboring vehicles in the local knowledge bases compared to the ground truth as a metric.**

I. Introduction

Connectivity plays a vital role to support modern intelligent transportation systems (sITS) [1]. These vehicles are equipped with a wide range of sensors producing large volume of data every minute. This data can be used by the vehicles themselves or can also be shared with other vehicles via local vehicle-to-vehicle (V2V) communication or via back end data centers using vehicle-to-cloud (V2C) communication.

Exchanging large data volumes between remote cloud servers and vehicles can easily overload the cellular communication channels as the channel capacity is limited [2]. In such scenarios, the multi-access edge computing (MEC) architecture [3] helps to reduce end-to-end latency by caching popular data contents. One downside of MEC is infrastructure deployment cost. To solve this problem, vehicles equipped with powerful computational units, large on-board storage, and communication capabilities can be integrated into the edge computing layer and offer edge services [4]–[6].

In previous research [5], it was assumed that vehicles participating in *vehicular micro clouds* coordinate among themselves using the same communication technology. However, modern vehicles may have heterogeneous multi-technology communication capabilities, i.e., direct V2V communication, V2C communication, or both. Additionally, vehicles may prefer to use only V2V communication because of extra costs incurred in using V2C. Integrating vehicles with different communication technologies within one *hybrid micro cloud* is challenging. This is mainly because of the need to rediscover optimal communication paths in this mobile environment.

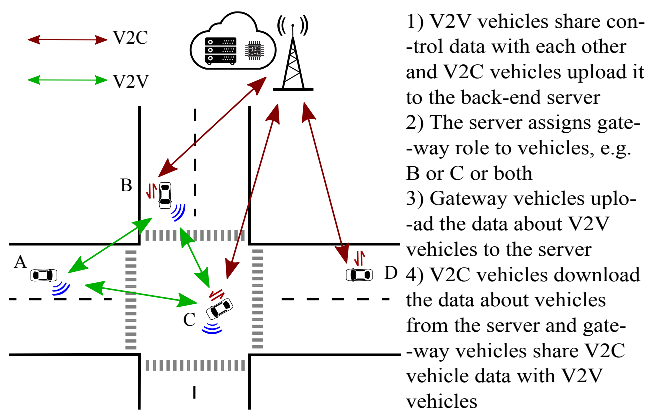

Figure 1. An example scenario showing vehicles with different communication capabilities, and the steps in which control information is shared between vehicles, and the server for hybrid micro cloud formation.

To enable communication between vehicles using different network technologies, a gateway is required. Such gateways can be part of the infrastructure or they get picked dynamically from the set of vehicles having both V2V and V2C interfaces. In this paper, we study the basic problem and also suggest ways to form hybrid micro clouds. There are several possibilities to select such gateway vehicles, e.g., all vehicles with both V2V and V2C can act as a gateway, or just one, or a subset of those vehicles. We provide preliminary performance results for this problem, focusing on the ratio of V2V and V2C vehicles, as well as those providing both technologies.

II. Hybrid Micro Clouds Formation

Vehicular micro clouds as introduced in [5] help coordinating virtual edge computing among vehicles, e.g., for cooperative perception or cooperative driving tasks. Given the heterogeneity of communication technologies of modern vehicles, some providing vehicle-to-vehicle, some vehicle-to-cloud communication, some both, connectivity between the vehicles in the local neighborhood as well as with the backend data centers becomes challenging. Such integration is the main challenge to form a *hybrid micro cloud*.

Figure 1 shows the scenario as well as the main steps involved in hybrid micro cloud formation. For example, vehicle

A has only V2V, vehicles B and C have both V2V and V2C, and vehicle D has only V2C capabilities. Using the V2V link, vehicles A, B, and C periodically share their available network interfaces, position, and the timestamp with each other. Similarly, vehicles B, C, and D periodically upload this data to the remote servers. Initially, the remote server has knowledge about only V2C capable vehicles. The server computes the first set of vehicles that become part of the hybrid micro cloud, and also assigns a gateway role to some of the vehicles with both V2V and V2C capabilities. The selected gateway vehicles start sharing the data received from V2V vehicles with the remote server. The resulting hybrid micro cloud membership is shared with all V2C capable vehicles and the gateways forward this to V2V only vehicles. In this paper, our gateway selection criteria is the distance of a vehicle from the center of hybrid micro cloud and the street on which a vehicle is driving.

This way, not only the hybrid micro cloud is formed but also cooperative awareness within the micro cloud as well as in the virtual counterpart in the backend data center is updated. Many ITS applications require exactly such information for cooperative driving and collision avoidance applications. Thus, the relevant question is how accurate the resulting position information is compared to the ground truth.

III. Initial Performance Study

To evaluate the performance of our designed hybrid micro cloud formation algorithm, we conducted simulations in a Manhattan Grid scenario with street length of 200 m. A hybrid micro cloud is formed around intersections with a radius of 100 m. Formed hybrid micro clouds in the simulation had about 18 cars on average. V2V communication was carried on 5.89 GHz channel with 10 MHz bandwidth and 6 Mbit/s data rate. V2C communication was carried using 15 resource blocks and MAX C/I LTE scheduling. All vehicles periodically announce their current positions with an update interval of 0.1 s, using either V2V or V2C communication. Gateway vehicles forward the received information immediately to the cloud or local neighbors, respectively. We looked at the position error by comparing position data in the local knowledge base with their actual position. This error also gives us insights regarding delays experienced in sharing data between vehicles with different communication capabilities.

We study the performance for different penetration rates, i.e., percentage of vehicles with V2V only, V2C only, and both V2C and V2V communication capabilities. Figure 2 shows the results including standard deviation. Each facet in the plot is labeled with the fraction of V2V only and V2C only vehicles; the remaining vehicles feature both V2V and V2C technologies.

We can see that the error is minimum when position data is shared via a direct V2V interface. This is also the smallest logical communication path within a hybrid micro cloud. The largest error is seen in the hybrid category. This refers to the position data exchange using gateway vehicles. In this case, the logical communication path is the longest, i.e., the position data is first received from V2V vehicles by gateway vehicles via V2V communication, which then uploaded to the remote server

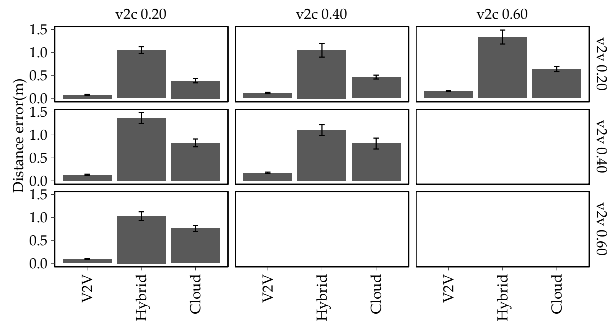

Figure 2. Comparison of known position data of the hybrid micro cloud members in the local knowledge base with their actual position.

over V2C link and later downloaded by other V2C vehicles or data is first uploaded by a V2C vehicle which is downloaded by a gateway vehicle and shared to a neighboring V2V vehicle using direct V2V communication. The error in cloud category is slightly less, as the communication path involves a network connection to the remote server.

IV. Conclusion and Future Work

In this paper, we study the communication paths in vehicular virtual edge computing using heterogeneous vehicle-to-vehicle (V2V) and vehicle-to-cloud (V2C) communication. Hybrid micro clouds are small group of connected vehicles sharing data and helping to offload computationally heavy tasks. These vehicles may or may not be able to communicate with each other directly. This is a direct consequence of currently deployed communication technologies in modern vehicles. Consequently, there is a need for gateway vehicles that help exchanging data between such set of vehicles with mutually exclusive communication capabilities. We considered vehicles which have only V2V communication capabilities, only V2C communication capabilities, or both. Via simulations we found that longer logical communication paths involving gateways in a hybrid micro cloud add extra delay in sharing the data, however it is still comparable to the delay in information sharing over a V2C link. As future work, we plan to study gateway selection algorithms and the performance of a hybrid micro cloud operating larger data contents.

References

[1] F. Dressler, H. Hartenstein, O. Altintas, and O. K. Tonguz, "Inter-Vehicle Communication – Quo Vadis," *IEEE Communications Magazine (COMMAG)*, vol. 52, no. 6, pp. 170–177, Jun. 2014.

[2] J. Pillmann, B. Sliwa, J. Schmutzler, C. Ide, and C. Wietfeld, "Car-to-Cloud Communication Traffic Analysis Based on the Common Vehicle Information Model," in *85th IEEE Vehicular Technology Conference (VTC 2017-Spring)*, Sydney, Australia, Jun. 2017.

[3] ETSI, "Mobile Edge Computing (MEC), Framework and Reference Architecture," ETSI, GS MEC 003 V1.1.1, Mar. 2016.

[4] F. Hagenauer, T. Higuchi, O. Altintas, and F. Dressler, "Efficient Data Handling in Vehicular Micro Clouds," *Elsevier Ad Hoc Networks*, vol. 91, p. 101 871, Aug. 2019.

[5] F. Dressler, G. S. Pannu, F. Hagenauer, M. Gerla, T. Higuchi, and O. Altintas, "Virtual Edge Computing Using Vehicular Micro Clouds," in *IEEE International Conference on Computing, Networking and Communications (ICNC 2019)*, Honolulu, HI: IEEE, Feb. 2019.

[6] L. Liu, C. Chen, Q. Pei, S. Maharjan, and Y. Zhang, "Vehicular Edge Computing and Networking: A Survey," *Mobile Networks and Applications*, pp. 1145–1168, Jun. 2021.