Assessment of Available Edge Computing Resources in SDN-VANETs by a Fuzzy-Based System Considering Trustworthiness as a New Parameter

Ermioni Qafzezi[1](✉), Kevin Bylykbashi[1], Phudit Ampririt[1], Makoto Ikeda[2], Leonard Barolli[2], and Makoto Takizawa[3]

[1] Graduate School of Engineering, Fukuoka Institute of Technology (FIT), 3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan
eqafzezi@gmail.com, bylykbashi.kevin@gmail.com, iceattpon12@gmail.com

[2] Department of Information and Communication Engineering, Fukuoka Institute of Technology (FIT), 3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan
makoto.ikd@acm.org, barolli@fit.ac.jp

[3] Department of Advanced Sciences, Faculty of Science and Engineering, Hosei University, 3-7-2, Kajino-machi, Koganei-shi, Tokyo 184-8584, Japan
makoto.takizawa@computer.org

Abstract. In this paper, we propose a fuzzy-based system to determine the processing capability of neighboring vehicles in Software Defined Vehicular Ad hoc Networks (SDN-VANETs) considering vehicle trustworthiness as a new parameter. The computational, networking and storage resources of vehicles comprise the Edge Computing resources in a layered Cloud-Fog-Edge architecture. A vehicle which needs additional resources to complete certain tasks and process various data can use the resources of the neighboring vehicles if requirements to realize such operations are fulfilled. We propose a new fuzzy-based system to assess the processing capability of each neighbor and based on the final value, we can determine whether the edge layer can be used by the vehicles in need. The proposed system takes into consideration the available resources of the neighbors, their trustworthiness value and the predicted contact duration between them and the vehicle. Our system takes also into account the neighbors willingness to share their resources and determines the processing capability for each neighbor. We evaluate the system by computer simulations. Helpful neighbors are the trustworthy ones that are predicted to be within the vehicle communication range for a while and have medium/large amount of available resources.

1 Introduction

The long distances separating homes and workplaces/facilities/schools as well as the traffic present in these distances make people spend a significant amount of time in vehicles. Thus, it is important to offer drivers and passengers ease of

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2021

L. Barolli et al. (Eds.): 3PGCIC 2020, LNNS 158, pp. 102–112, 2021.
https://doi.org/10.1007/978-3-030-61105-7_11

driving, convenience, efficiency and safety. This has led to the emerging of Vehicular Ad hoc Networks (VANETs), where vehicles are able to communicate and share important information among them. VANETs are a relevant component of Intelligent Transportation Systems (ITS) which offer more safety and better transportation.

VANETs are capable to offer numerous services such as road safety, enhanced traffic management, as well as travel convenience and comfort. To achieve road safety, emergency messages must be transmitted in real-time, which stands also for the actions that should be taken accordingly in order to avoid potential accidents. Thus, it is important for the vehicles to always have available connections to infrastructure and to other vehicles on the road. On the other hand, traffic efficiency is achieved by managing traffic dynamically according to the situation and by avoiding congested roads, whereas comfort is attained by providing in-car infotainment services.

The advances in vehicle technology have made possible for the vehicles to be equipped with various forms of smart cameras and sensors, wireless communication modules, storage and computational resources. While more and more of these smart cameras and sensors are incorporated in vehicles, massive amounts of data are generated from monitoring the on-road and in-board status. This exponential growth of generated vehicular data, together with the boost of the number of vehicles and the increasing data demands from in-vehicle users, has led to a tremendous amount of data in VANETs [14]. Moreover, applications like autonomous driving require even more storage capacity and complex computational capability. As a result, traditional VANETs face huge challenges in meeting such essential demands of the ever-increasing advancement of VANETs.

The integration of Cloud-Fog-Edge Computing in VANETs is the solution to handle complex computation, provide mobility support, low latency and high bandwidth. Each of them serves different functions, but also complements eachother in order to enhance the performance of VANETs. Even though the integration of Cloud, Fog and Edge Computing in VANETs solves significant challenges, this architecture lacks mechanisms needed for resource and connectivity management because the network is controlled in a decentralized manner. The prospective solution to solve these problems is the augmentation of Software Defined Networking (SDN) in this architecture.

The SDN is a promising choice in managing complex networks with minimal cost and providing optimal resource utilization. SDN offers a global knowledge of the network with a programmable architecture which simplifies network management in such extremely complicated and dynamic environments like VANETs [13]. In addition, it will increase flexibility and programmability in the network by simplifying the development and deployment of new protocols and by bringing awareness into the system, so that it can adapt to changing conditions and requirements, i.e., emergency services [5]. This awareness allows SDN-VANET to make better decisions based on the combined information from multiple sources, not just individual perception from each node.

In previous works, we have proposed an intelligent approach to manage the cloud-fog-edge resources in SDN-VANETs using fuzzy logic. We presented a cloud-fog-edge layered architecture which is coordinated by an intelligent system that decides the appropriate resources to be used by a particular vehicle in need of additional computing resources. The proposed system was implemented in the SDN Controller (SDNC) and in the vehicles equipped with an SDN module [9–12]. The main objective was to achieve a better management of these resources. The appropriate resources to be used by the vehicle were decided by considering the vehicle relative speed with its neighbors, the number of neighbors, the time-sensitivity and the complexity of the task to be accomplished.

In another recent work [8], we proposed a fuzzy-based system that could assess the edge computing resources by considering the available resources of the neighboring vehicles. We determined the processing capability for each neighbor separately, hence helpful neighbors could be discovered. In this work, we include the neighbors trustworthiness to better assess their processing capability or in other words, to attain a trustworthy processing capability value. If the neighbors are not trustworthy and do not have sufficient resources to process the data and complete the tasks, the resources to be used by the vehicle are those of fog or cloud.

The remainder of the paper is as follows. In Sect. 2, we present an overview of Cloud-Fog-Edge SDN-VANETs. In Sect. 3, we describe the proposed fuzzy-based system. In Sect. 4, we discuss the simulation results. Finally, conclusions and future work are given in Sect. 5.

2 Cloud-Fog-Edge SDN-VANETs

While cloud, fog and edge computing in VANETs offer scalable access to storage, networking and computing resources, SDN provides higher flexibility, programmability, scalability and global knowledge. In Fig. 1, we give a detailed structure of this novel VANET architecture. It includes the topology structure, its logical structure and the content distribution on the network. As it is shown, it consists of Cloud Computing data centers, fog servers with SDNCs, road-side units (RSUs), RSU Controllers (RSUCs), Base Stations and vehicles. We also illustrate the infrastructure-to-infrastructure (I2I), vehicle-to-infrastructure (V2I), and vehicle-to-vehicle (V2V) communication links. The fog devices (such as fog servers and RSUs) are located between vehicles and the data centers of the main cloud environments.

The safety applications data generated through in-board and on-road sensors are processed first in the vehicles as they require real-time processing. If more storing and computing resources are needed, the vehicle can request to use those of the other adjacent vehicles, assuming a connection can be established and maintained between them for a while. With the vehicles having created multiple virtual machines on other vehicles, the virtual machine migration must be achievable in order to provide continuity as one/some vehicle may move out of the communication range. However, to set-up virtual machines on the nearby

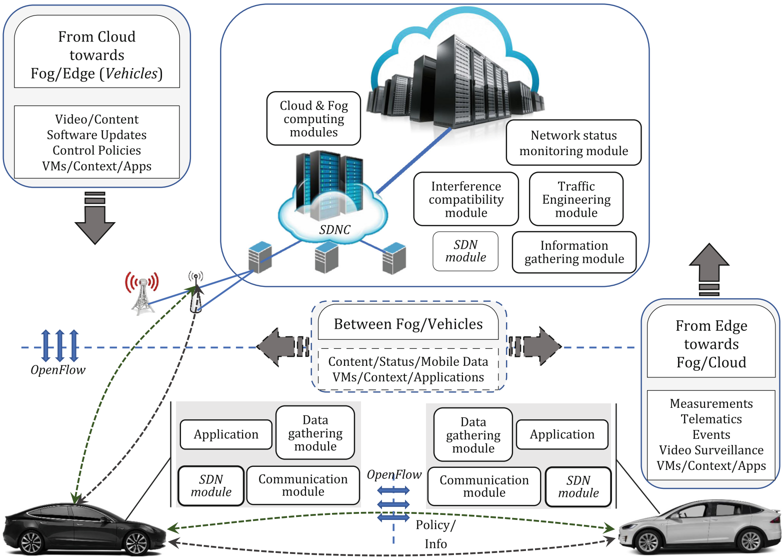


Fig. 1. Logical architecture of cloud-fog-edge SDN-VANET with content distribution.

vehicles, multiple requirements must be met and when these demands are not satisfied, the fog servers are used.

Cloud servers are used as a repository for software updates, control policies and for the data that need long-term analytics and are not delay-sensitive. On the other side, SDN modules which offer flexibility and programmability, are used to simplify the network management by offering mechanisms that improve the network traffic control and coordination of resources. The implementation of this architecture promises to enable and improve the VANET applications such as road and vehicle safety services, traffic optimization, video surveillance, telematics, commercial and entertainment applications.

3 Proposed Fuzzy-Based System

In this section, we present our proposed fuzzy based system. A vehicle that needs storage and computing resources for a particular application can use those of neighboring vehicles, fog servers or cloud data centers based on the application requirements. For instance, for a temporary application that needs real-time processing, the vehicle can use the resources of adjacent vehicles if the requirements to realize such operations are fulfilled. Otherwise, it will use the resources of fog servers, which offer low latency as well. Whereas real-time applications require the usage of edge and fog layer resources, for delay tolerant applications, vehicles can use the cloud resources as these applications do not require low latency.

The proposed system is implemented in the SDNC and in the vehicles which are equipped with SDN modules. If a vehicle does not have an SDN module, it

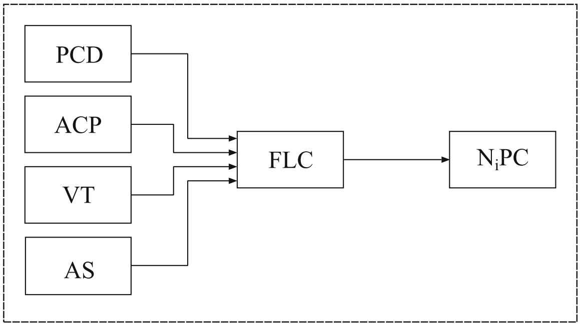


Fig. 2. Proposed system structure.

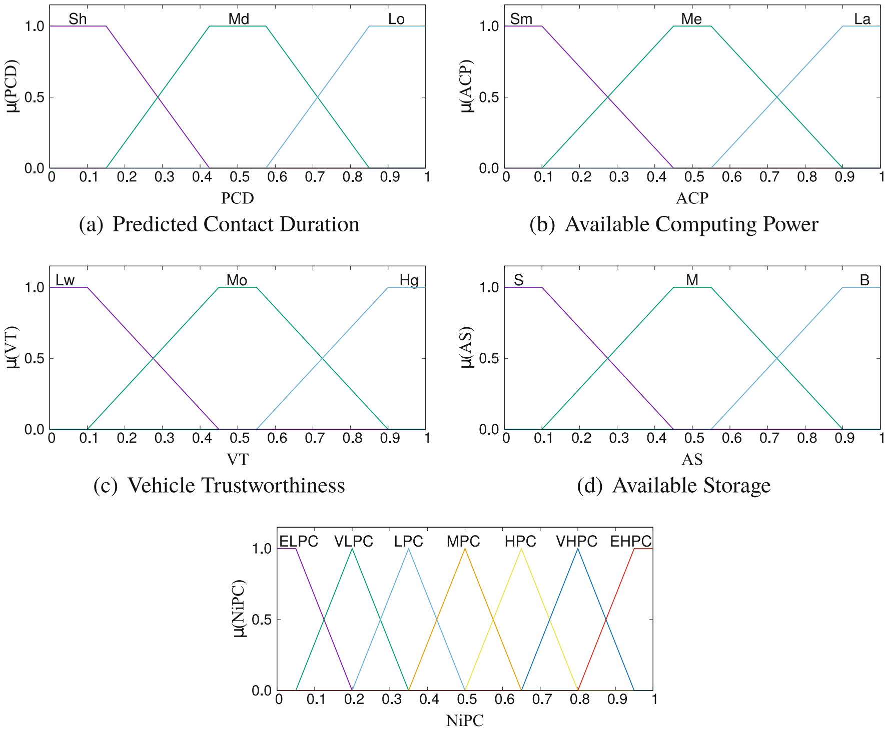
sends the information to SDNC which sends back its decision. The system uses the beacon messages received from the adjacent vehicles to extract information such as their current position, velocity, direction, available computing power, available storage, trustworthiness, and based on the received data, the processing capability of each adjacent vehicle is decided.

The structure of the proposed system is shown in Fig. 2. For the implementation of our system, we consider four input parameters: Predicted Contact Duration (PCD), Available Computing Power (APC), Available Storage (AS) and Vehicle Trustworthiness (VT) to determine the Neighbor *i* Processing Capability (NiPC).

PCD: In a V2V communication, the duration of the communication session is important since it determines the amount of data to be exchanged and the services that can be performed. A *vehicle* which needs additional resources will create virtual machines on the neighbors that are willing to lend their resources, therefore the contact duration becomes even more important since much more time is needed to accomplish these tasks than just performing a data exchange.

ACP: Vehicles might be using their computing power for their own applications but a reserved amount can be allocated to help other vehicles in need to complete certain tasks. Vehicles let their neighbors know that they are willing to share their resources and how much they want to share. In other words, they decide the amount of physical processor cores and the amount of memory that a particular *vehicle* can use.

VT: It is important to consider trustworthiness as it can help to make better assessments of the neighbors helpfulness. Trust is defined as the ratio of the successfully accomplished tasks to the number of tasks this vehicle is asked to help with. A trustworthy vehicle is a vehicle that has been given a high trust value by other vehicles and has been helpful to other vehicles in the network.



(a) Predicted Contact Duration

(b) Available Computing Power

(c) Vehicle Trustworthiness

(d) Available Storage

(e) Neighbor *i* Processing Capability

Fig. 3. Membership functions.

AS: The neighbors should have a specific amount of storage so the *vehicle* can run the virtual machines. This storage is used also to store data after completing specific tasks out of all the tasks these neighbors are asked to accomplish.

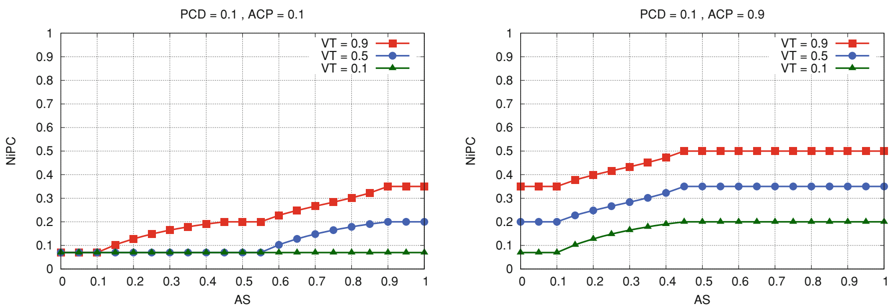
NiPC: The output parameter values consist of values between 0 and 1, with the value 0.5 working as a border to determine if a neighbor is capable of helping out the *vehicle*. A NiPC ≥ 0.5 means that this neighbor i has the required conditions to help the *vehicle* to complete its tasks.

We consider fuzzy logic to implement the proposed systems because our system parameters are not correlated with each other. Having three or more parameters which are not correlated with each other results in a non-deterministic polynomial-time hard (NP-hard) problem and fuzzy logic can deal with these problems. Moreover, we want our systems to make decisions in real time and fuzzy systems can give very good results in decision making and control problems [1–4,6,7,15,16].

The input parameters are fuzzified using the membership functions showed in Fig. 3(a), (b), (c) and (d). In Fig. 3(e) are shown the membership functions used for the output parameter. We use triangular and trapezoidal membership functions because they are suitable for real-time operation. The term sets for each linguistic parameter are shown in Table 1. We decided the number of term sets by carrying out many simulations. In Table 2, we show the Fuzzy Rule Base (FRB) of our proposed system, which consists of 81 rules. The control rules have the form: IF "conditions" THEN "control action". For instance, for Rule 1: "IF PCD is Sh, ACP is Sm, VT is Lw and AS is S, THEN NiPC is ELPC" or for Rule 50: "IF PCD is Md, ACP is La, VT is Mo and AS is M, THEN NiPC is HPC".

Table 1. Parameters and their term sets for our proposed system.

Parameters	Term sets
Predicted Contact Duration (PCD)	Short (Sh), Medium (Md), Long (Lo)
Available Computing Power (ACP)	Small (Sm), Medium (Me), Large (La)
Vehicle Trustworthiness (VT)	Low (Lw), Moderate (Mo), High (Hg)
Available Storage (AS)	Small (S), Medium (M), Big (B)
Neighbor i Processing Capability (NiPC)	Extremely Low Processing Capability (ELPC), Very Low Processing Capability (VLPC), Low Processing Capability (LPC), Moderate Processing Capability (MPC), High Processing Capability (HPC), Very High Processing Capability (VHPC), Extremely High Processing Capability (EHPC)

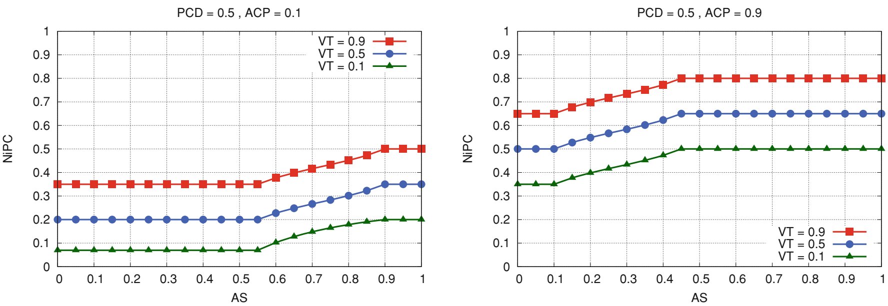


(a) PCD = 0.1, ACP = 0.1 (b) PCD = 0.1, ACP = 0.9

Fig. 4. Simulation results for PCD = 0.1.

Table 2. The FRB of the proposed system.

No	PCD	ACP	VT	AS	NiPC	No	PCD	ACP	VT	AS	NiPC	No	PCD	ACP	VT	AS	NiPC
1	Sh	Sm	Lw	S	ELPC	28	Md	Sm	Lw	S	ELPC	55	Lo	Sm	Lw	S	VLPC
2	Sh	Sm	Lw	M	ELPC	29	Md	Sm	Lw	M	ELPC	56	Lo	Sm	Lw	M	LPC
3	Sh	Sm	Lw	B	ELPC	30	Md	Sm	Lw	B	VLPC	57	Lo	Sm	Lw	B	LPC
4	Sh	Sm	Mo	S	ELPC	31	Md	Sm	Mo	S	VLPC	58	Lo	Sm	Mo	S	LPC
5	Sh	Sm	Mo	M	ELPC	32	Md	Sm	Mo	M	VLPC	59	Lo	Sm	Mo	M	MPC
6	Sh	Sm	Mo	B	VLPC	33	Md	Sm	Mo	B	LPC	60	Lo	Sm	Mo	B	MPC
7	Sh	Sm	Hg	S	ELPC	34	Md	Sm	Hg	S	LPC	61	Lo	Sm	Hg	S	MPC
8	Sh	Sm	Hg	M	VLPC	35	Md	Sm	Hg	M	LPC	62	Lo	Sm	Hg	M	HPC
9	Sh	Sm	Hg	B	LPC	36	Md	Sm	Hg	B	MPC	63	Lo	Sm	Hg	B	HPC
10	Sh	Me	Lw	S	ELPC	37	Md	Me	Lw	S	VLPC	64	Lo	Me	Lw	S	LPC
11	Sh	Me	Lw	M	ELPC	38	Md	Me	Lw	M	LPC	65	Lo	Me	Lw	M	MPC
12	Sh	Me	Lw	B	VLPC	39	Md	Me	Lw	B	LPC	66	Lo	Me	Lw	B	MPC
13	Sh	Me	Mo	S	ELPC	40	Md	Me	Mo	S	LPC	67	Lo	Me	Mo	S	MPC
14	Sh	Me	Mo	M	VLPC	41	Md	Me	Mo	M	MPC	68	Lo	Me	Mo	M	HPC
15	Sh	Me	Mo	B	LPC	42	Md	Me	Mo	B	MPC	69	Lo	Me	Mo	B	HPC
16	Sh	Me	Hg	S	VLPC	43	Md	Me	Hg	S	MPC	70	Lo	Me	Hg	S	HPC
17	Sh	Me	Hg	M	LPC	44	Md	Me	Hg	M	HPC	71	Lo	Me	Hg	M	VHPC
18	Sh	Me	Hg	B	MPC	45	Md	Me	Hg	B	HPC	72	Lo	Me	Hg	B	VHPC
19	Sh	La	Lw	S	ELPC	46	Md	La	Lw	S	LPC	73	Lo	La	Lw	S	MPC
20	Sh	La	Lw	M	VLPC	47	Md	La	Lw	M	MPC	74	Lo	La	Lw	M	HPC
21	Sh	La	Lw	B	VLPC	48	Md	La	Lw	B	MPC	75	Lo	La	Lw	B	HPC
22	Sh	La	Mo	S	VLPC	49	Md	La	Mo	S	MPC	76	Lo	La	Mo	S	HPC
23	Sh	La	Mo	M	LPC	50	Md	La	Mo	M	HPC	77	Lo	La	Mo	M	VHPC
24	Sh	La	Mo	B	LPC	51	Md	La	Mo	B	HPC	78	Lo	La	Mo	B	VHPC
25	Sh	La	Hg	S	LPC	52	Md	La	Hg	S	HPC	79	Lo	La	Hg	S	VHPC
26	Sh	La	Hg	M	MPC	53	Md	La	Hg	M	VHPC	80	Lo	La	Hg	M	EHPC
27	Sh	La	Hg	B	MPC	54	Md	La	Hg	B	VHPC	81	Lo	La	Hg	B	EHPC



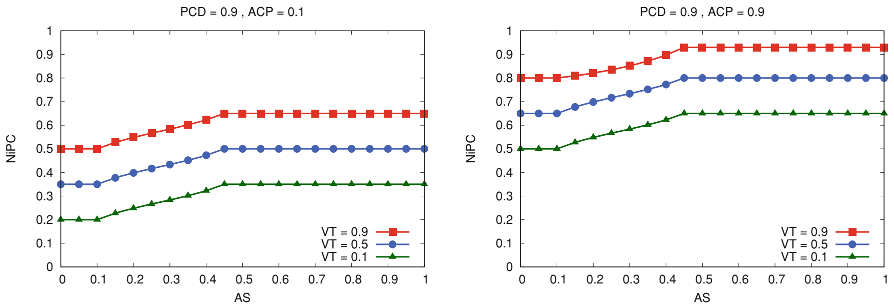
(a) PCD = 0.5, ACP = 0.1 (b) PCD = 0.5, ACP = 0.9

Fig. 5. Simulation results for PCD = 0.5.

4 Simulation Results

We used FuzzyC to carry out the simulations and the results are shown in Fig. 4, Fig. 5 and Fig. 6. We show the relation between NiPC and AS for different PCD, ACP and VT values. PCD and ACP are considered as constant parameters. The considered VT values are 0.1, 0.5 and 0.9 which represent a low, moderate and high value of trustworthiness, respectively.

We take into consideration three scenarios: when PCD is short (PCD = 0.1), medium (PCD = 0.5) and long (PCD = 0.9). In Fig. 4, are shown the scenarios when PCD is short. We consider two cases for each scenario: when available computing power is small (ACP = 0.1) and large (ACP = 0.9). As we can see from Fig. 4(a), a neighbor with a small computing power cannot help out the vehicle even if it has a high trustworthiness value. However, when ACP is large, we see that the neighbors with a high VT can be considered as helpful to process the data, given that these neighbors have at least a moderate amount of storage (see Fig. 4(b)). This is due to the large ACP and especially to the high VT which indicates that this vehicle has been really helpful to other vehicles in the past, and it is worth taking this neighbor into consideration as it will make a really potential neighbor if an increase in PCD happens (see Fig. 5(b)).



(a) PCD = 0.9, ACP = 0.1 (b) PCD = 0.9, ACP = 0.9

Fig. 6. Simulation results for PCD = 0.9.

Figure 6 shows the scenario when PCD = 0.9. This means that these neighbors will be within the vehicle communication range for a long time. We can see that, if these neighboring vehicles are willing to lend a large amount of their resources to the vehicle, they can be considered as helpful neighbors even if their trustworthiness value is low. Since it is predicted that they will be within the communication range for a long time and are willing to lend a large amount of resources, it is worth presuming that they will process the data and accomplish the tasks successfully.

5 Conclusions

In this paper, we proposed a new fuzzy-based system to assess the available edge computing resources in a layered Cloud-Fog-Edge architecture for SDN-VANETs. Our proposed system determines if a neighboring vehicle is capable to help a vehicle that lacks the appropriate resources to accomplish certain tasks based on PCD, ACP, AS and VT. After calculating the processing capability for each available neighbor, our previous proposed Fuzzy System for Resource Management can select the appropriate layer in terms of data processing. We evaluated our proposed system by computer simulations. From the simulations results, we conclude as follows.

- For short PCD, the neighboring vehicles which do not have high ACP are not capable to help other vehicles in need, regardless their high value of AS, even if their VT value is high.
- For medium PCD, once a trustworthy vehicle has a certain ACP, it can be considered as a potential neighbor regardless its AS value.
- The highest value of NiPC is achieved when the neighboring vehicle has a long PCD, large ACP, high VT and a medium/big AS.

In the future, we would like to make extensive simulations to evaluate the proposed system and compare the performance with other systems.

References

1. Bylykbashi, K., Elmazi, D., Matsuo, K., Ikeda, M., Barolli, L.: Effect of security and trustworthiness for a fuzzy cluster management system in VANETs. Cogn. Syst. Res. **55**, 153–163 (2019). https://doi.org/10.1016/j.cogsys.2019.01.008
2. Bylykbashi, K., Qafzezi, E., Ikeda, M., Matsuo, K., Barolli, L.: Fuzzy-based Driver Monitoring System (FDMS): implementation of two intelligent FDMSs and a testbed for safe driving in VANETs. Future Gener. Comput. Syst. **105**, 665–674 (2020). https://doi.org/10.1016/j.future.2019.12.030
3. Kandel, A.: Fuzzy Expert Systems. CRC Press Inc., Boca Raton (1992)
4. Klir, G.J., Folger, T.A.: Fuzzy Sets, Uncertainty, and Information. Prentice Hall, Upper Saddle River (1988)
5. Ku, I., Lu, Y., Gerla, M., Gomes, R.L., Ongaro, F., Cerqueira, E.: Towards software-defined VANET: architecture and services. In: 13th Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET), pp. 103–110 (2014)
6. McNeill, F.M., Thro, E.: Fuzzy Logic: A Practical Approach. Academic Press Professional Inc., San Diego (1994)
7. Munakata, T., Jani, Y.: Fuzzy systems: an overview. Commun. ACM **37**(3), 69–77 (1994)
8. Qafzezi, E., Bylykbashi, K., Ampririt, P., Ikeda, M., Barolli, L., Takizawa, M.: A fuzzy-based system for assessment of available edge computing resources in a cloud-fog-edge SDN-VANETs architecture. In: International Conference on Network-Based Information Systems, pp. 10–19. Springer (2020)
9. Qafzezi, E., Bylykbashi, K., Ikeda, M., Matsuo, K., Barolli, L.: Coordination and management of cloud, fog and edge resources in SDN-VANETs using fuzzy logic: a comparison study for two fuzzy-based systems. Internet Things **11**, 100169 (2020)
10. Qafzezi, E., Bylykbashi, K., Ishida, T., Matsuo, K., Barolli, L., Takizawa, M.: Resource management in SDN-VANETs: coordination of cloud-fog-edge resources using fuzzy logic. In: International Conference on Emerging Internetworking, Data & Web Technologies, pp. 114–126. Springer (2020)

11. Qafzezi, E., Bylykbashi, K., Spaho, E., Barolli, L.: An intelligent approach for resource management in SDN-VANETs using fuzzy logic. In: International Conference on Broadband and Wireless Computing, Communication and Applications, pp. 747–756. Springer (2019)
12. Qafzezi, E., Bylykbashi, K., Spaho, E., Barolli, L.: A new fuzzy-based resource management system for SDN-VANETs. Int. J. Mob. Comput. Multimedia Commun. (IJMCMC) **10**(4), 1–12 (2019)
13. Truong, N.B., Lee, G.M., Ghamri-Doudane, Y.: Software defined networking-based vehicular adhoc network with fog computing. In: 2015 IFIP/IEEE International Symposium on Integrated Network Management (IM), pp. 1202–1207 (2015)
14. Xu, W., Zhou, H., Cheng, N., Lyu, F., Shi, W., Chen, J., Shen, X.: Internet of vehicles in big data era. IEEE/CAA J. Automatica Sinica **5**(1), 19–35 (2018)
15. Zadeh, L.A., Kacprzyk, J.: Fuzzy Logic for the Management of Uncertainty. Wiley, New York (1992)
16. Zimmermann, H.J.: Fuzzy control. In: Fuzzy Set Theory and Its Applications, pp. 203–240. Springer (1996)