International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 2, April 2023, pp. 2206~2213
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i2.pp2206-2213

Smart optimization in 802.11p media access control protocol for vehicular ad hoc network

Shahirah Mohamed Hatim[1], Haryani Haron[2], Shamsul Jamel Elias[3], Nor Shahniza Kamal Bashah[2]
[1]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Perak, Malaysia
[2]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia
[3]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Kedah, Malaysia

Article Info

Article history:

Received Dec 23, 2021
Revised Sep 15, 2022
Accepted Oct 11, 2022

Keywords:

Optimization
Packet delivery ratio
Taguchi method
Vehicle-to-infrastructure
Vehicular ad hoc network

ABSTRACT

The innovative idea presented in this research is that advancements in automotive networks and embedded devices can be used to assess the impact of congestion control on throughput and packet delivery ratio (PDR), or so-called multimedia content delivery. Vehicle networking and the distribution of multimedia content have become essential factors in getting packets to their intended recipients due to the availability of bandwidth. Vehicle-to-infrastructure (V2I) communication systems are crucial in vehicular ad hoc networks (VANETs), which permit vehicles to connect by distributing and delivering traffic data and transmission packet schemes. High levels of mobility and changing network topology necessitate dispersed monitoring and execution for congestion control. The amount of traffic congestion for packet transfers could be reduced by enhancing congestion management in terms of throughput and PDR percentages. In a highway setting, the Taguchi approach has been used to optimize the parameters for congestion control. Based on throughput and PDR performance measures, this technique minimizes superfluous traffic information and lowers the likelihood of network congestion. The simulation results have shown that the proposed approach performs better since it increases network performance while effectively utilizing bandwidth. The effectiveness of the suggested technique is evaluated using a typical VANETs scenario for V2I communication while driving on a highway.

Corresponding Author:

Haryani Haron
Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA
40450 Shah Alam, Selangor, Malaysia
Email: harya265@uitm.edu.my

1. INTRODUCTION

Vehicular ad hoc networks or namely (VANETs) refer to a division of mobile ad hoc networks (MANETs) in which the network's participant vehicles serve as mobile nodes. This technology was made available as a way to reduce traffic congestion. It has several unique characteristics that enable it to outperform standard MANETs, including a dynamic topology, high mobility, and high network density. Applications for VANETs are divided into two categories: applications for safety and applications for non-safety [1]–[10]. Applications for safety could be found in drivers' information, such as critical events involving connectivity, dependability, and delay. The purpose of the safety application is to avoid traffic accidents by communicating vital information to road users allied to VANETs to save their lives [2], [4], [10]. In contrast, instead of using delay-sensitive applications, non-safety applications are utilized to improve the transportation system and services that require them. In VANETs, the testing scenarios for transportation services include cities, highways, and intersections. The structure of VANETs is illustrated in Figure 1 [1], [11].

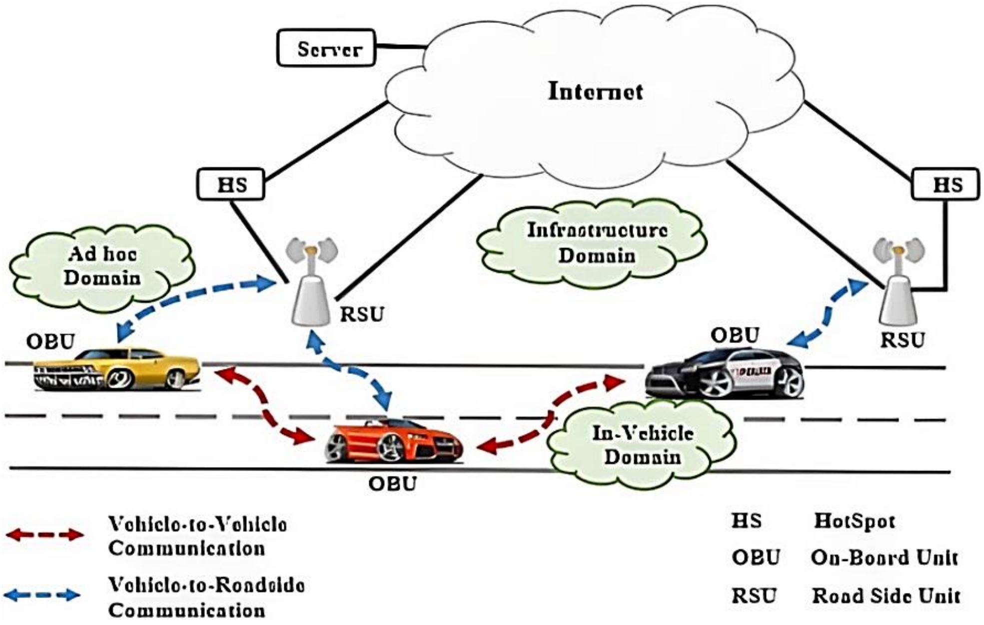


Figure 1. The structure of VANETs

In the highway scenario, the speed between vehicles is low when they are traveling in a group, but it is high when roadside units (RSUs) are present. In all traffic situations, vehicles going in the same and opposing directions can be assessed. For instance, when more RSUs can be put in the city, driving conditions there are typically slower than those on the highway. With all the skyscrapers acting as barriers, the route across the city could be more complicated, and the driver's pattern could also be unpredictable. There are more RSUs accessible between the transmitter and receiver state circumstances during intersectional traffic [12].

Direct communication between nodes occurs without using an access point (AP). While in VANETs, the highways are outfitted through static RSU and mobile nodes with on board units (OBUs) [1], [2], [4]. It is therefore possible to assess the performance using functional metrics, node density, high node mobility, and unexpected communication situations. In VANETs, the communication between cars using the RSUs infrastructure is acknowledged as V2I communications, and the embedded OBUs in the vehicles can share and transfer data with one another [1].

VANETs are intended to offer a variety of comforts to drivers and passengers, but more significantly for non-safety uses [1], [13], [14]. Irrespective of the environment, with a relative speed of up to 180 km/h and a range of one kilometer, VANETs are able to provide 802.11p communication with RSUs as well as other vehicles. VANETs can provide a wealth of information, including position, speed, emergency warnings, and roadside entertainment, but if users react poorly to the technology, this wealth of information could delay implementation and increase packet latency [1]–[4], [11], [15], [16].

The connectedness of the nodes' communication and the delivery of packets to their intended locations are maintained by network performance optimization. Designing the new network parameter is hence an expensive endeavor to improve network protocols. For VANETs topology changes and to maintain connectivity and communication between vehicles, increasing the number of RSUs could be highly expensive [1], [2], [4], [14]. It places a strong emphasis on network optimization and improvement rather than relying exclusively on alterations to the network's parameters.

This strategy necessitates that the method is intelligent enough to enhance circumstances even in error-free environments driven by the need to eliminate traffic congestion and delays [15]. In this research, the Taguchi approach is used to optimize the vehicular networks for packet delivery ratio (PDR) and throughput. The evaluation condition for this study is the highway scenario.

2. THE PROPOSED METHOD

2.1. Taguchi method as the optimization procedure

Genichi Taguchi initially presented the Taguchi technique in 1960. The goal is to manufacture high-quality goods at cheaper prices while minimizing process variance and planning a strong experimental design [17], [18]. The Taguchi method is a type of experimental design used to examine how different variables affect the mean and variation of a process performance parameter.

Taguchi's method is considered as an optimization approach where it relies on an orthogonal array (OA) design that can be used to obtain settings that are close to near-optimal [15], [19]. Taguchi, which offers a methodical approach towards selecting the controlling factors on any experimental simulation, OA stands as a crucial parameter. Manufacturing processes see the most widespread application of Taguchi's technique, followed by other technical specialties including wireless communications, power electronics, and electromagnetic [16], [18], [20], [21]. Figure 2 demonstrates the steps of Taguchi optimization [15].

To ensure better network performance, Taguchi was employed to optimize the radio network's parameters. Vertical sectorization will lead to a capacity gain that can be realized. Vertical sectorization was also utilized to improve radio networks, outperforming conventional networks by increasing user throughput in the 50th and 5th percentiles [14], [22].

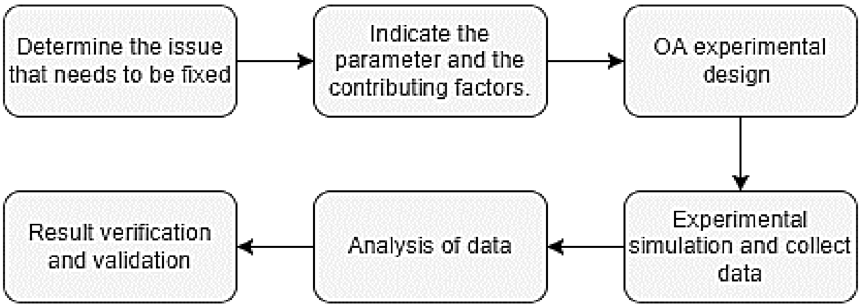


Figure 2. Phases in Taguchi optimization

2.2. Planning phase

The goal of this study is to optimize the vehicular network's control parameters for maximum throughput and optimal packet delivery rates for VANET congestion control. Packet size in kilobyte (KB) and RSU distance in m are the next control factors that are meant to be optimized. The three sources of noise are the number of nodes, the frequency of packet creation, and the speed of mobility. Table 1 lists the levels of variance for the control factors. The range of packet sizes examined is 25 to 125 KB. Along the route, five RSU stations are set up at intervals of 250 meters, ranging from 1 meter to 1,000 meters. We used the media access control (MAC) protocol 802.11p. Ad hoc on-demand distance vector (AODV) is used the routing protocols. Table 2 shows the degree of fluctuation of noise factors.

Table 1. Level of variations of control factors

Parameters	Low	High
wifiPreambleMode	Long	Short
SlotTime	5 µs	25 µs
rtsThresholdBytes	500 with *rts*	2346 without *rts/cts*
minSuccessThreshold	5	20
successCoef	2.0	8.0

Table 2. Levels of variations for noise factors

Parameters	1	2	3	4	5
Packet size (KB)	25	50	75	100	125
Number of Vehicles	10	20	30	40	50

3. RESEARCH METHOD

The OMNeT++ 4.6 simulator is used to conduct the experiments [15]. This open-source software is categorized as a software-defined network (SDN), which enables system network framework optimization through design based on user perception of the proposed framework. The INET framework [23], [24], and INET-MANET [25] of the OMNeT++ serve as the foundation for all MAC and routing protocols.

The input data used to evaluate the traffic generator is user datagram protocol (UDP). During the 250 simulated seconds, the simulation scenario was carried out in a setting with wireless vehicular mobility and the generation of three random seeds. Table 3 displays the fundamental simulation setup parameters and Figure 3 shows the VANETs base station module implementing the AODV routing for 802.11p wireless [13].

Table 3. Experimental parameter sets

Parameter	Values
Number of vehicles	60
Number of RSUs	5
Simulation times	250s
Traffic type	UDP
Routing protocol	AODV
.bitrate	27Mbps
.wlan	IEEE 802.11p
.message length	512 bytes
Random Number Generator	3 [15]

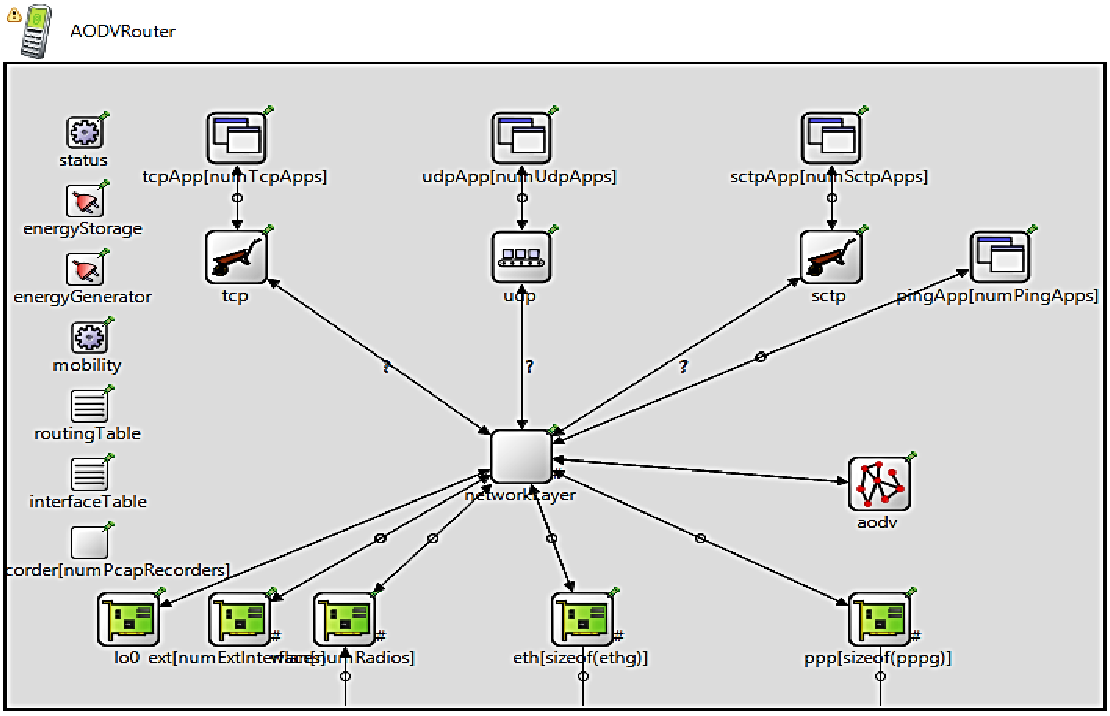


Figure 3. VANETs base station module implementing the AODV routing for 802.11p wireless

An *.ini* file would be used to use and set the necessary parameters of the simulation modules in this network as well as other simulation components, such as bit rate, rate limit, mobility speed, and transmit interval, as shown in Figure 2. To establish and develop a hierarchy style, single modules like relay units are connected via gates and merged to produce a compound module.

3.1. Analysis phase

For each experiment under testing, the signal-to-noise (SN) ratio must be computed in order to ascertain the impact each factor has on the output. The SN value reveals the difference between an experimental process's mean and its variance. The following SN ratio, known as the larger-the-better ratio, should be determined in the scenario where performance parameters are to be maximized:

$$SN_i = -10log\left[\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{y_u^2}\right] \tag{1}$$

regarding the nominal-the-best scenario, this is when a particular value is most desirable. Following are the steps to calculate the SN ratio:

$$SN_i = 10log\frac{\bar{y_i}^2}{s_i^2} \tag{2}$$

where:

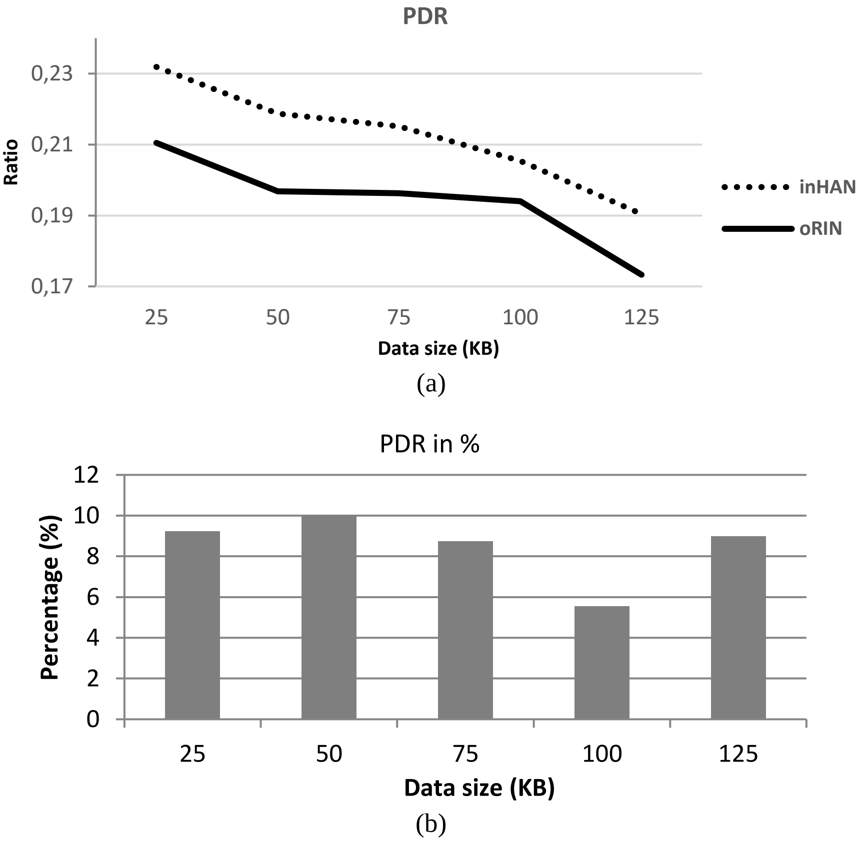
$$\bar{y}_i = \frac{1}{N_i}\sum_{u=1}^{N_i} y_{i,u} \tag{3}$$

$$s_i^2 = \frac{1}{N_i-1}\sum_{u=1}^{N_i}\left(y_{i,u} - \bar{y}_i\right) \tag{4}$$

In the experimental phase, *y* indicates the mean response of the experiment, *i* indicates the experimentation number, *u* is the trial number and *Ni* is the number of trials for experiment *i*. As mentioned earlier, safety and non-safety applications are the two main attentions in VANETs [1], [12]. Both have contrast requirements with low-level quality of service (QoS). However, the demands for non-safety applications are focusing more on throughput sensitivity than delay. Therefore, to acquire the best congestion management design for VANETs, especially for non-safety applications, it is recommended to take into account the larger-the-better performance metric for both PDR and throughput sensitivity. The performance indicators being assessed in this research are PDR and throughput.

4. RESULTS AND DISCUSSION

This section explained the results of the research and at the same time it provides a comprehensive discussion. Performance of the PDR and throughput of the proposed work is observed. It is evaluated for before and after optimization. The result is shown in Figures 4(a) and 4(b).



(a)

(b)

Figure 4. PDR performance of congestion control framework for optimization of AODV routing over VANETs (a) ratio before (oRIN) and after (inHAN) and (b) percentage for before (oRIN) and after (inHAN)

Figure 4 shows the accuracy and completeness of the VANETs' AODV congestion control protocol architecture for non-safety or multimedia applications after optimization. Based on Table 4, there is an improvement following optimization that, according to the average PDR, is about 8.5 percent. As a result, packet loss is also decreased. Given that the updated AODV protocol reduces the latency of routing activity from the source to the destination, the PDR is on a declining trend starting at 25 KB and is lower for a certain period of time.

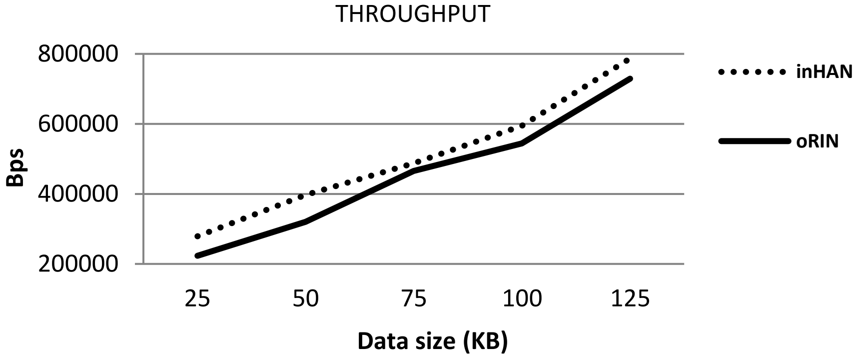
In principle, the AODV protocol's properties for congestion control on multimedia applications demonstrate viability impact on PDR of VANETs. The PDR decreases when there is a significant rise in data traffic activity, topological changes, and broken links to the following hops or transmissions because data size increases at intervals of 25 to 125 KB. The graphs in Figure 4 and Table 4 demonstrate the mean S/N greater is better to produce the best and highest PDR with the best fit parameter setting through the parameter screening stage, based on the Taguchi design.

When we choose data size as our primary requirement in a high static and dynamic environment, the corresponding framework performs better in terms of bandwidth efficiency after optimization. Compared to the previous optimization, Figures 5(a) and 5(b) demonstrates successful data transmission to the intended recipient (throughput). Shorter hops and the basic route recovery failure phase of AODV in vehicle ad hoc networks both contributed to an increase in throughput.

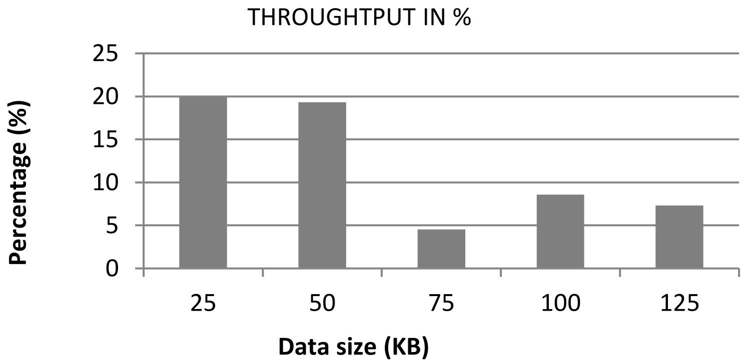
According to Table 4, the average throughput improved after optimization by about 11.93%. Additionally, there is less packet loss. Since the updated AODV protocol reduces the delay of routing activities from the source to the destination, the throughput is on the rise and is at a high level for a specific time starting at 50 KB.

Table 4. Normalization percentage of congestion improvement

Data Size	25	50	75	100	125	Average
PDR	9.24	10.02	8.74	5.56	8.99	8.51
Throughput	19.95	19.30	4.51	8.58	7.33	11.93



(a)



(b)

Figure 5. Performance throughput for congestion control framework (a) before (oRIN) and after (inHAN) optimization of AODV routing over VANETs, and (b) performance percentage of throughput for before and after optimization of AODV routing over VANETs

5. CONCLUSION

The performance of VANETs for non-safety or multimedia applications is influenced by a variety of direct and indirect variables. These elements can be divided into two groups: noise factors and planned or control elements. For a wide range of design elements, including MAC protocols, routing protocols, network architecture, and situations, a robust optimization technique is needed. In order to increase the proportion of congestion control for throughput and PDR, or in other words, multimedia applications in VANETs, this article developed the Taguchi optimization approach.

In this study, two control parameters and three noise factors were taken into account. The variables are optimum for packet delivery ratio and throughput. The greatest rank value between two performances revealed the various aspects when they were examined. A tested factor in increasing network throughput and PDR is data size. Performance in terms of throughput is significantly impacted by RSU distance, although PDR is less affected. As a result, the data size, which is one of the key controlling parameters in this experiment, is significantly impacted by non-safety or multimedia applications that are throughput and PDR sensitive. It is advised that more parameters be investigated or included in future work for non-safety applications when optimizing congestion control for VANETs.

ACKNOWLEDGEMENTS

The authors wish to thank Universiti Teknologi MARA, Malaysia and Ministry of Higher Education of Malaysia for funding this research.

REFERENCES

[1] S. J. Elias *et al.*, “Congestion control in vehicular adhoc network: a survey,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 13, no. 3, pp. 1280–1285, Mar. 2019, doi: 10.11591/ijeecs.v13.i3.pp1280-1285.

[2] S. M. Hatim, S. J. Elias, N. Awang, and M. Y. Darus, “VANETs and internet of things (IoT): A discussion,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 12, no. 1, pp. 218–224, Oct. 2018, doi: 10.11591/ijeecs.v12.i1.pp218-224.

[3] E. C. Eze, S.-J. Zhang, E.-J. Liu, and J. C. Eze, “Advances in vehicular ad-hoc networks (VANETs): Challenges and road-map for future development,” *International Journal of Automation and Computing*, vol. 13, no. 1, pp. 1–18, Feb. 2016, doi: 10.1007/s11633-015-0913-y.

[4] N. Taherkhani, “Congestion control in vehicular ad hoc networks,” University of Montreal, 2015.

[5] N. B. Truong, G. M. Lee, and Y. Ghamri-Doudane, “Software defined networking-based vehicular adhoc network with fog computing,” in *2015 IFIP/IEEE International Symposium on Integrated Network Management (IM)*, May 2015, pp. 1202–1207, doi: 10.1109/INM.2015.7140467.

[6] W. Liang, Z. Li, H. Zhang, S. Wang, and R. Bie, “Vehicular ad hoc networks: architectures, research issues, methodologies, challenges, and trends,” *International Journal of Distributed Sensor Networks*, vol. 11, no. 8, Aug. 2015, doi: 10.1155/2015/745303.

[7] A. Dua, N. Kumar, and S. Bawa, “QoS-aware data dissemination for dense urban regions in vehicular ad hoc networks,” *Mobile Networks and Applications*, vol. 20, no. 6, pp. 773–780, Dec. 2015, doi: 10.1007/s11036-014-0553-4.

[8] M. S. Talib, B. Hussin, and A. Hassan, “Converging VANET with vehicular cloud networks to reduce the traffic congestions: A review,” *International Journal of Applied Engineering Research*, vol. 12, no. 21, pp. 10646–10654, 2017.

[9] J. Cheng, J. Cheng, M. Zhou, F. Liu, S. Gao, and C. Liu, “Routing in internet of vehicles: A review,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 5, pp. 2339–2352, Oct. 2015, doi: 10.1109/TITS.2015.2423667.

[10] C. M. Silva, B. M. Masini, G. Ferrari, and I. Thibault, “A survey on infrastructure-based vehicular networks,” *Mobile Information Systems*, vol. 2017, pp. 1–28, 2017, doi: 10.1155/2017/6123868.

[11] M. K. Hossain, S. Datta, S. I. Hossain, and J. Edmonds, “ResVMAC: A novel medium access control protocol for vehicular ad hoc networks,” *Procedia Computer Science*, vol. 109, pp. 432–439, 2017, doi: 10.1016/j.procs.2017.05.413.

[12] M. Y. Darus, M. S. Z. Abidin, S. J. Elias, and Z. Zainol, “Optimizing congestion control for non safety messages in VANETs using taguchi method,” in *Computational Science and Technology*, 2018, pp. 74–87.

[13] R. Jain, “A congestion control system based on VANET for small length roads,” *Annals of Emerging Technologies in Computing*, vol. 2, no. 1, pp. 17–21, Jan. 2018, doi: 10.33166/AETiC.2018.01.003.

[14] V. K. Vankanti and V. Ganta, “Optimization of process parameters in drilling of GFRP composite using Taguchi method,” *Journal of Materials Research and Technology*, vol. 3, no. 1, pp. 35–41, Jan. 2014, doi: 10.1016/j.jmrt.2013.10.007.

[15] S. A. Soleymani *et al.*, “A Secure trust model based on fuzzy logic in vehicular ad hoc networks with fog computing,” *IEEE Access*, vol. 5, pp. 15619–15629, 2017, doi: 10.1109/ACCESS.2017.2733225.

[16] H. Hanizam, M. S. Salleh, M. Z. Omar, and A. B. Sulong, “Optimisation of mechanical stir casting parameters for fabrication of carbon nanotubes–aluminium alloy composite through Taguchi method,” *Journal of Materials Research and Technology*, vol. 8, no. 2, pp. 2223–2231, Apr. 2019, doi: 10.1016/j.jmrt.2019.02.008.

[17] H. Mohamed, M. H. Lee, S. Salleh, B. Sanugi, and M. Sarahintu, “Ad-hoc network design with multiple metrics using Taguchi’s loss function,” in *Proceedings of the 2011 International Conference on Electrical Engineering and Informatics*, Jul. 2011, pp. 1–5, doi: 10.1109/ICEEI.2011.6021659.

[18] M. Aamir, S. Tu, M. Tolouei-Rad, K. Giasin, and A. Vafadar, “Optimization and modeling of process parameters in multi-hole simultaneous drilling using Taguchi method and fuzzy logic approach,” *Materials*, vol. 13, no. 3, Feb. 2020, doi: 10.3390/ma13030680.

[19] K.-E. Aslani, D. Chaidas, J. Kechagias, P. Kyratsis, and K. Salonitis, “Quality performance evaluation of thin walled PLA 3D printed parts using the Taguchi method and grey relational analysis,” *Journal of Manufacturing and Materials Processing*, vol. 4, no. 2, May 2020, doi: 10.3390/jmmp4020047.

[20] S. Dastoor, U. Dalal, and J. Sarvaiya, “Comparative analysis of optimization techniques for optimizing the radio network parameters of next generation wireless mobile communication,” in *2017 Fourteenth International Conference on Wireless and Optical Communications Networks (WOCN)*, Feb. 2017, pp. 1–6, doi: 10.1109/WOCN.2017.8065843.
[21] J. E. Ribeiro, M. B. César, and H. Lopes, “Optimization of machining parameters to improve the surface quality,” *Procedia Structural Integrity*, vol. 5, pp. 355–362, 2017, doi: 10.1016/j.prostr.2017.07.182.
[22] S. E. Nai, Z. Lei, S. H. Wong, and Y. H. Chew, “Optimizing radio network parameters for vertical sectorization via Taguchi’s method,” *IEEE Transactions on Vehicular Technology*, vol. 65, no. 2, pp. 860–869, Feb. 2016, doi: 10.1109/TVT.2015.2401030.
[23] D. Klein and M. Jarschel, “An OpenFlow extension for the OMNeT++ INET framework,” *Proceedings of the Sixth International Conference on Simulation Tools and Techniques*, 2013, doi: 10.4108/simutools.2013.251722.
[24] S. J. Elias, M. N. M. Warip, S. Mansor, S. R. M. Dawam, and A. R. Mansor, “Experimental model of congestion control vehicular ad hoc network using OMNET++,” in *Proceedings of the International Conference on Computing, Mathematics and Statistics (iCMS 2015)*, Singapore: Springer Singapore, 2017, pp. 25–35.
[25] M. Y. Arafat and S. Moh, “Routing protocols for unmanned aerial vehicle networks: A survey,” *IEEE Access*, vol. 7, pp. 99694–99720, 2019, doi: 10.1109/ACCESS.2019.2930813.

BIOGRAPHIES OF AUTHORS

Shahirah Mohamed Hatim is an academia at the Faculty of Computer and Mathematical Sciences Universiti Perak Branch Tapah Campus, Perak, Malaysia. Her research interests include internet of vehicles (IoV), internet of things (IoT) and artificial intelligence algorithms. She is a member of IEEE and currently pursuing her PhD in Computer Science focusing on Vehicular Adhoc Communication. She can be contacted at email: shahirah88@uitm.edu.my.

Haryani Haron is a Professor in Computer Science with Universiti Teknologi MARA (UiTM) since 2018. She is currently the Dean of the Faculty of Computer and Mathematical Sciences, UiTM. She has authored or co-authored more than 100 refereed journals, conference papers, and book chapters. Her research interests include the applications of knowledge management, data analytics, and technology foresight. She can be contacted at email: harya265@uitm.edu.my.

Shamsul Jamel Elias is a lecturer at the Universiti Teknologi MARA Kedah Branch, Malaysia. His expertise areas are vehicular ad hoc network and performance evaluation in congestion control mechanisms. He is a senior member of IEEE and a member of IAENG. He has published his research results in conferences and journals. He can be reached at email: shamsulje@uitm.edu.my.

Nor Shahniza Kamal Bashah is an Associate Professor at the Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Malaysia. Her research interest involved in the field of Mobile and Wireless Communication and Semantic Web. She can be contacted at shahniza@uitm.edu.my.