Research Article

Sourav Kumar Bhoi, Sanjaya Kumar Panda*, Chittaranjan Mallick, and Kalyan Kumar Jena

Impact of road architecture and design on performance of city-based VANETs

<https://doi.org/10.1515/comp-2020-0217>

received November 17, 2019; accepted November 30, 2020

Abstract: Vehicular communication is the communication between the vehicles to provide intelligent transportation systems (ITSs) services to the end users. It is the most advance and emerging wireless technology in ad hoc network. On the other hand, construction of roads has a great impact in forwarding the data to the destination. As vehicles are moving with high speeds, the architecture of roads can change the performance of routing and data forwarding in the vehicular ad hoc network (VANET). If the construction of the roads in a city area is planned with intelligent junctions, flyovers, multilane, etc., then the performance of the system increases. In this paper, we have analyzed the impact of road elements like intersections, flyovers, multilane, buildings, hills, etc., on VANET routing and find solutions for the problems related to the performance of the system. We also simulate the impact of these elements in VANET routing and analyzed the performance using OMNeT++ network simulator and SUMO traffic simulator. The performance is studied by comparing standard GSR and GPSR position-based routing protocols.

Keywords: road construction, vehicular ad hoc network, vehicular communication, intersections, flyovers, multi-lane, obstacles

1 Introduction

VANET is an advanced wireless network, which provides many safety applications to the drivers and passengers [1–8]. The main aim of implementing VANET technology is to reduce the accidents in the city areas. It also provides many ITS services to the end users, like media downloading, transmission control protocol/Internet protocol (TCP/IP) services, information sharing, safety systems, etc. This technology is deployed in some parts of the world, like the United States of America (USA), Japan, European Union, etc. Many projects are implemented in the USA, like intelligent vehicle initiative, vehicle safety communications, etc. Japan implemented projects, like the second stage of advanced safety vehicle (ASV-2), Japan automobile research institute (JARI), etc. In Europe, there are many projects like car-2-car communication consortium (C2C CC), FleetNet, network on wheels, etc. Nowadays, vehicular communication is a necessary wireless technology to get safe from road accidents and get services, like e-commerce, cloud services, tracking vehicles, etc. To develop the VANET technology all over the world, researchers are working in the areas of routing, security, information sharing, cloud services, etc. In this paper, we mainly concentrate on routing [1,2,9], which is mostly required to forward the data from the source to the destination. On the other hand, road construction has a great impact on the performance of VANET [10]. The performance of VANET is mainly known for how fast the data are transmitted to the destination or how fast the service is provided to the destination vehicle. Therefore, routing and data forwarding play an important role in transmission of data. However, they are strongly affected by road architectures and designs. There are many elements in the roads, which have an impact in communication between the vehicles, like intersections, flyovers, multi-lane, and obstacles (buildings and hills) [3,11]. Intersection plays an important role in communication between the source vehicle and the destination vehicle that can be used for calculation of shortest paths. Flyover also plays an important role in communication between the vehicles

* **Corresponding author: Sanjaya Kumar Panda**, Department of Computer Science and Engineering, National Institute of Technology, Warangal 506004, India, e-mail: sanjayauc@gmail.com

Sourav Kumar Bhoi: Department of Computer Science and Engineering, Parala Maharaja Engineering College (Govt.), Berhampur 761003, India, e-mail: souravbhoi@gmail.com

Chittaranjan Mallick: Department of Mathematics, Parala Maharaja Engineering College (Govt.), Berhampur 761003, India, e-mail: cmallick75@gmail.com

Kalyan Kumar Jena: Department of Computer Science and Engineering, Parala Maharaja Engineering College (Govt.), Berhampur 761003, India, e-mail: kalyan.cse@pmec.ac.in

by sending the data through it. Moreover, sending data through a multilane helps to reduce the level of communication gaps between the vehicles because if multilanes are there then the density of vehicle may be high. Obstacles have a great impact on vehicular communication by blocking the communication, which reduces the performance of the system [3,11]. Figure 1 shows the impact of different road elements on vehicular communication.

Researchers are working mainly to enhance the performance of the VANET system by finding new solutions to the problems that are related to routing. Chang *et al.* [3] proposed geocasting protocols to send the messages to the geocasting regions by using a small flooding area in order to survive from the obstacles. Giordano *et al.* [12] have proposed a model, called CORNER, to estimate the obstacles in the city area by using the maps. Martinez *et al.* [13] have proposed radio propagation models to study the effect of the models in system performance. Mahajan *et al.* [14] have worked in developing simulation models for streets, multilane, traffic, etc. and analyzed the effect on packet delivery and delays. Boban and Vinhoza [15] have proposed a simulation model for vehicles as obstacles and studied the effect of vehicles in system performance. Khazaal *et al.* [16] have studied the effect of obstacles in video quality. Many such research works mainly based on VANET mobility models, data transmission models, packet error models, routing, security, automation, performance analysis, etc. are presented in ref. [17–59].

From the literature survey and according to our knowledge, it is observed that no such work has been done in this area where the impact of road construction and design has been studied, to see the performance of VANETs. This work explored the areas in a simpler manner by highlighting all possible issues and provided solutions related to the issues.

The major contributions of this paper are stated as follows:

1. In this work, we analyze the impact of road elements in the performance of VANET. First, we consider the intersections to evaluate VANET performance. Here, we evaluate that if an intersection is intelligently constructed, then the vehicles communicate in a well manner and there is less number of communication gap between the vehicles. We also evaluate that if two intersections are far apart from each other, then there is a chance of link breakage between the vehicles.
2. Second, we evaluate that the flyovers over the roads reduce the distances (i.e., shortest path generation) to the destination, which enhances the VANET performance. Here, we discuss about flyover vehicle to flyover vehicle communication (FV2FV) and ground vehicle to flyover vehicle communication (GV2FV/ FV2GV) and analyzed that it reduces the end-to-end delay.
3. Third, we evaluate the effect of singlelane and multilane on vehicular communication and analyzed that multilane has high density. As a result, there is less chance of link breakages in these areas.
4. At last, we evaluate the effect of obstacles, like buildings, hills, trees, cars, any objects, etc. in vehicular communication and analyzed that they reduce the performance of VANET.
5. The above scenarios are implemented using OMNeT++ network simulator and SUMO traffic simulator to study the performance. The performance is evaluated using two standard routing protocols such as GSR [2] and GPSR [2].

The paper is organized as follows. Section 2 presents the effect of road elements in VANET communication. Section 3 presents the simulation results of the effect of road elements. At last, we conclude in Section 4.

2 Impact of road construction on VANET performance

The performance of VANET mainly depends on the design and planned architectures of the roads in the city areas. The performance parameters, like end-to-end delay, packet delivery ratio, throughput, etc., depend on the way in which the roads are constructed. In this section, the network model and communication between the vehicles are discussed. Then, we analyze the effect of the road elements such as intersection, flyover, lane, and obstacles on VANET performance.

Figure 1: Impact of different road elements on vehicular communication.

Figure 2: City-based VANET architecture.

2.1 Network model

We consider the following assumptions that are related to the whole system. The city area is considered as a graph, where the roads connecting the two networks are assumed as an edge and the intersections are assumed as the vertices. Figure 2 shows the architecture of city-based VANETs. The roads also consist of road side units (RSUs) which are fixed nodes for transmission of data to the cloud or used for advertisements. Each vehicle beacons at a particular interval of time to broadcast its information (such as, speed, location, and identification (ID)) at a rate of 1 beacon/100 ms. The neighboring vehicles

maintain a neighbor table and update data. The vehicles use global positioning system services with maps to know their own positions. We also assume that the time to send a data from one vehicle (V_1) to another (V_2) is $(\tau_t + \tau_o)_{V_1 V_2}$, where τ_t is the transmission delay and τ_o is the other delays, like processing delay, propagation delay, and queuing delay.

2.2 Effect of intersection

In a road network, intersections play an important role to connect the roads and help the vehicles to select a new path. At the intersection region, the density (λ) of the vehicles is very high than the vehicles between the two intersections. This is because at the junction region, from all directions vehicles arrive or wait to choose a new path. However, between the junctions there may be less vehicles at some time when the density is less. We divide the intersections as simple intersection and intelligent intersection, respectively. Simple intersection is a type of intersection in which vehicle spends too much time, because of lack of planned architecture. Intelligent intersection is another type of intersection in which the vehicles spend less time, because of its planned architecture. In Figure 3, vehicles want to move to a region ($x \times y$), but due to simple traffic architecture, they stay there for a t time, which creates a communication link breakage region ($x \times y$). If a data packet reaches at the intersection and the vehicle carrying the data has calculated the shortest path, then it has to stay for t time. This architecture increases the time delay due to the generation of the communication gaps. The vehicle waits until a vehicle from north side to east side or when the traffic from the

Figure 3: Simple intersection.

intersection is released. In Figure 4, an intelligent intersection is shown in which the vehicles are moving without a traffic light system. This is because of the small flyover, which reduces the traffic congestion. Here, the density of vehicles is also higher and they can pass to any direction, without staying at the intersection. As the roads are busy, if a data packet reaches at the intersection, then it can be easily routed to any routes in order to reach the destination. This is due to no communication gaps at the intersections. This reduces the end-to-end delay by quickly transmitting the data to the destination.

Theorem 1. *If data are forwarded through an intelligent intersection, then end-to-end delay reduces.*

Proof: Let us consider Figure 3 in which the number of vehicles in the region $(x \times y)$ at any time t is less (for example, no vehicles). If there are n number of vehicles $(V_1, V_2, \dots, V_n)$ moving through the intersection, then there is a chance of communication gap. If data are carried by a vehicle at the intersection and the route is calculated in the eastern direction, then the vehicle carries the data for τ_c time until a new vehicle moves in that direction. This increases the end-to-end delay. Let us assume that we have m simple intersections $(i_1, i_2, \dots, i_m)$ and destination (D) . At a particular instant of time, if a vehicle V_1 carries the data and it has determined the route to be $V_1-i_1-i_2-\dots-i_m-D$. Then the delay (T_1) to transmit the data in this route is calculated as follows.

$$T_1 = (\tau_t + \tau_o)_{V_1 i_1} + \tau_c + (\tau_t + \tau_o)_{i_1 i_2} + \tau_c + \dots + (\tau_t + \tau_o)_{i_m D} \quad (1)$$

where, τ_c is the carry and forward delay.

From Figure 4, we observe that the vehicles are moving, without spending any time. As a result, there is a less chance of communication gap generation. Therefore, delay (T_2) is calculated as follows.

$$T_2 = (\tau_t + \tau_o)_{V_1 i_1} + (\tau_t + \tau_o)_{i_1 i_2} + \dots + (\tau_t + \tau_o)_{i_m D} \quad (2)$$

From equations (1) and (2), we conclude that $T_2 < T_1$.

Theorem 2. *If the intersections are far away from each other, then there is a chance of link breakage between the vehicles.*

Proof: As we know intersection connects the roads and there is a chance of high density in that region. If the intersections are far away from each other, then the driver behavior (especially, those drivers drive the vehicle at a high speed) changes and there is chance of link breakage between the vehicles. Let us consider Figures 5 and 6 in which there are four (i_1, i_2, i_3, i_4) and two (i_5, i_6) number of intersections. Let the path length from i_1 to i_4 is denoted as $PL_{i_1 i_4}$ and this path has more intersections. As a result, the density of vehicles (λ) is also more. Let $PL_{i_1 i_4}$ has m number of vehicles and $PL_{i_5 i_6}$ has n number of vehicles, respectively, where $m > n$. Here, we assume that $\lambda_1 > \lambda_2$ and the path lengths are same (i.e., $PL_{i_1 i_4} = PL_{i_5 i_6}$). The probability of getting m vehicles in path i_1 to i_4 is given as follows.

$$P(m) = ((\lambda_1 A_1)^m / m!) e^{-\lambda_1 A_1} \quad (3)$$

where, λ_1 is the density of the vehicles in $PL_{i_1 i_4}$ and A_1 is the area of the road between i_1 and i_4 . Note that we use the Poisson distribution to represent the probability.

Figure 4: Intelligent intersection.

Figure 5: Path with four intersections.

The probability of getting n vehicles in path i_5 to i_6 is given as follows.

$$P(n) = ((\lambda_2 A_2)^n / n!) e^{-\lambda_2 A_2} \quad (4)$$

where, λ_2 is the density of the vehicles in $PL_{i_5 i_6}$ and A_2 is the area of the road between i_5 and i_6 . As $m > n$ and $P(m) > P(n)$ (from equations (3) and (4)), it is clear that the link breakage problem depends on the density of the vehicle. Hence, if the number of vehicles is more, then there is a high chance of getting vehicle in the communication range and there is no link breakage.

2.3 Effect of Flyover

Flyovers are constructed to reduce the traffic in which there is a free flow of vehicles. Flyover passes over a road and connects to a new road. The vehicles which are moving in the flyover are called flyover vehicles (FV) and the vehicles moving in the ground are called ground vehicles (GV). If data communication occurs between the vehicles, then the

communication can be GV2GV (ground vehicle to ground vehicle), FV2FV, and GV2FV/FV2GV (ground vehicle to flyover vehicle/flyover vehicle to ground vehicle). This communication helps in reducing the end-to-end delay by reducing the distance. Figure 6 shows the flyover communication.

Theorem 3. Forwarding data through a flyover can reduce the path length to the destination.

Proof: From Figure 7, if we are not considering the flyover, then the path length to reach D from source S (PL_{SD}) is given as follows.

$$PL_1 = Si_1 + i_1 i_2 + i_2 i_5 + i_5 i_8 + i_8 D \quad (5)$$

If the flyover is used, then the PL_2 is given by taking the two-intersection points p and q and it is shown as follows.

$$\begin{aligned} PL_2 &= Si_1 + i_1 p + pq + qi_8 + i_8 D \\ &= Si_1 + i_1 p + \int_a^b (1 + (dy/dx)^2)^{1/2} dx + qi_8 + i_8 D \end{aligned} \quad (6)$$

Figure 6: Path with two intersections.

Figure 7: Flyover communication.

where, curve $(p - q)$ length is shown in the equation (6). From Figure 8, we assume that the curve tends to a straight line and the length pi_2 and i_2q are straight lines. According to Pythagoras theorem, $(pi_2 + i_2q) > (p - q)$. From equations (5) and (6), $PL_1 > PL_2$. As distance reduces, the time delay also reduces.

Theorem 4. *FV2FV and GV2FV/FV2GV communications reduce the link breakage problem.*

Proof: From Figure 9, we see that V_1 encounters no vehicle in its communication range and the link breaks with V_3 as it moves too fast. For the link survivability, V_1 communicates with V_2 , which is a FV (GV2FV). Then V_2 sends the data to V_3 in its range (FV2FV). After this, V_3

sends the data to V_4 (FV2GV) and this process continues until D is reached. Previously, the link is broken with V_4 , but the above communications make the data transmission and avoid link breakage problem.

Let the link created in Figure 8 is $V_1 \rightarrow V_2 \rightarrow V_3 \rightarrow V_4 \rightarrow V_5$. The time delay T_1 to send the data through this continuous link is calculated as follows.

$$T_1 = (\tau_t + \tau_o)_{V_1 V_2} + (\tau_t + \tau_o)_{V_2 V_3} + (\tau_t + \tau_o)_{V_3 V_4} + (\tau_t + \tau_o)_{V_4 V_5} \quad (7)$$

Let T_2 is the time delay in which the GV carries the data until a new GV is encountered and the time delay is calculated as follows.

$$T_2 = \tau_c + (\tau_t + \tau_o)_{V_1 V_4} + (\tau_t + \tau_o)_{V_4 V_5} \quad (8)$$

From equations (7) and (8), there is no guarantee of finding a vehicle, which may increase the τ_c time. Therefore, $T_2 > T_1$ and we conclude that FV vehicles help in transmitting the data rapidly to the destination.

Figure 8: City area with flyover.

2.4 Effect of lane

Lanes are designed to manage the traffic by marking lines on the roads. It helps the vehicles to pass in a single line. By designing multilane two-way, a huge number of vehicles can pass from one intersection to another. In this scenario, the density of vehicles increases between the intersections. Therefore, sending data packet in a route having highest connected lanes increases the performance of the system. There is a less chance of link break between the vehicles, which helps a source vehicle to send the data packet to the destination in an efficient rate. In Figure 10, we see that some of the intersections

Figure 9: Flyover communication with no link breakage.

are connected by a 2-lane or 3-lane (referred as multilane) and the data are transmitted in a route, which is highly connected. Here, the route, which is highly connected with the lanes, is $S \rightarrow i_1 \rightarrow i_4 \rightarrow i_5 \rightarrow i_6 \rightarrow i_9 \rightarrow D$.

Theorem 5. *Multilane reduces the effect of link failure.*

Proof: From Figure 11, we see that a 2-lane structure is constructed, which survives the network from link failure. V_1 encounters null vehicle in its communication range. The area $(x \times y)$ has no vehicle. But, the data are transmitted in a multilane road. As a result, V_1 transmits the data to V_2 , which is present in its communication range. However, this vehicle is moving in the third row. The link is created as follows. $V_1 \rightarrow V_2 \rightarrow V_3 \rightarrow V_4 \rightarrow V_5$, where $\rightarrow$ is the link between the vehicles. If T is the delay to transmit the data from V_1 to V_5 , then it is presented as follows.

$$T = (\tau_t + \tau_o)_{V_1 V_2} + (\tau_t + \tau_o)_{V_2 V_3} + (\tau_t + \tau_o)_{V_3 V_4} + (\tau_t + \tau_o)_{V_4 V_5} \quad (9)$$

From equation (9), we see that there is no carry and forward mechanism and this helps the system to reduce the end-to-end delay.

2.5 Effect of obstacle

The obstacles are the physical things in the environment, which block the communication between the vehicles in a VANET implemented area. When roads are constructed in a region with obstacles, then obstacles have great effect in communication between the vehicles. Obstacles are of many types like buildings, hills, trees, towers, lakes, vehicles, etc. In city areas, there is a chance of encountering the obstacles. This obstacle blocks the

Figure 10: City area with lanes.

Figure 11: 2-lane structure.

signal from the sender to the receiver [30,31]. This results in packet error, retransmissions, packet discard, etc.

Theorem 6. *If number of hop count increases, the delay increases and packet delivery ratio decreases.*

Proof: There are two cases in which the obstacles block the systems communication and reduce the performance of the system. The two cases are discussed as follows.

Case 1: At the beaconing phase, the vehicles send their information (ID, speed, and location) to the neighboring vehicles. But, due to the obstacle (like Figure 12), V_1 is unable to send the current information about itself to V_3 and *vice versa*. Here, V_1 wants to send the data to V_3 , which is in its communication range, but it is not visible in the range (beaconing fails). This may increase the delay by sending the data to a next hop, which is nearer to V_1 or sends the data to a vehicle in different route, which is far away from the destination. Let T_1 is the delay to send the data directly to V_3 and T_2 is the delay to send the data via V_2 . The delays are mathematically represented as follows.

$$T_1 = (\tau_t + \tau_o)_{V_1 V_3} \quad (10)$$

$$T_2 = (\tau_t + \tau_o)_{V_1 V_2} + (\tau_t + \tau_o)_{V_2 V_4} \quad (11)$$

From equations (10) and (11), $T_2 > T_1$. This is due to increase of hop counts, which also leads to increase in the distance and delay.

Case 2: At the data transmission phase, there may be dropping of packets, which increases the time delay. Sending and resending the packet continuously reduces the performance of the system. Let the packets to be received is m and some of the packets are dropped due to obstacles. At last, n packets are received. As a result, the packet delivery ratio is reduced to (n/m) .

3 Simulation and results

In this section, the simulation and results are presented. Initially, simulation setup and assumptions taken during the simulation are discussed. The parameters considered for performance evaluation are end-to-end delay and

Figure 12: Obstacles in city area.

Table 1: Simulation setting for SUMO

Sl. No.	Parameters	Values
1	Area	3,000 × 3,000 m ²
2	Number of lanes	3 directions
3	Maximum speed of vehicles	30 m/s
4	Allowed maximum speed on edges	30.556 m/s
5	Maximum acceleration	3.0 m/s ²
6	Maximum deceleration	6.0 m/s ²
7	Driver imperfection	0.5
8	Number of vehicles	10–100
9	Vehicles type	3
10	Length of vehicle type	5, 7, 12 m
11	Number of intersections	9

Table 2: Simulation setting for network simulator

Sl. No.	Parameters	Values
1	Simulation time	300 s
2	Bitrate	6 Mbps
3	Packet generation rate	10 packets/s
4	Communication range of vehicle	300 m
5	Communication range of RSU	500 m
6	Update interval	0.1 s
7	IEEE	802.11p
8	Sensitivity	-80 dBm
9	Number of simulations	20

packet delivery ratio. We have considered four scenarios where the impact of road elements such as intersections, flyovers, multilanes, and obstacles are studied. In this simulation to study the performance comparison, we

have considered two standard routing protocols, GSR [2] and GPSR [2], for data transfer from source to the destination.

To carryout simulation, we have used the Veins hybrid framework simulator. This simulator uses IEEE 802.11p standard for communication. Since the framework is hybrid one, it uses OMNeT++ and Simulation of Urban Mobility (SUMO) as network and road traffic simulator, respectively [60,61]. These simulators are integrated using a Traffic Control Interface (TraCI). This interface provides the TCP connection between the network and road traffic simulator and maintains real time interaction between them. We simulate our work in Grid Map scenario. The configuration parameters for SUMO and OMNeT++ are provided in Tables 1 and 2, respectively. The results are the average of 20 simulation runs. The source and the destinations are randomly selected.

Figure 13: End-to-end delay in seconds for GSR in simple intersection and intelligent intersection scenario. **Figure 14:** End-to-end delay in seconds for GPSR in simple intersection and intelligent intersection scenario.

Figure 15: End-to-end delay in seconds for GSR in flyover communication and normal road communication scenario.

Figure 16: End-to-end delay in seconds for GPSR in flyover communication and normal road communication scenario.

Figure 17: End-to-end delay in seconds for GSR in single lane and multi-lane scenario.

Figure 18: End-to-end delay in seconds for GPSR in single lane and multi-lane scenario.

Scenario 1: In the first scenario, we have simulated the vehicles passing through simple intersection and intelligent intersection and analyzed the results by considering end-to-end delay. In the simple intersection, the vehicle will wait at the intersection (traffic delay). But, in the intelligent intersection, we have designed the route SUMO in such a manner that no vehicles are in waiting condition at the intersection, so data are forwarded in a faster manner. Figures 13 and 14 show that if the data are forwarded in a route with simple intersections, then the end-to-end delay is higher than the route with intelligent intersections because the vehicles wait at the intersections. However, if the density of vehicles increases, then the data will be transmitted quickly. From the two figures, it is observed that GPSR performs better than GSR routing protocol by showing less delay.

Scenario 2: In the second scenario, we have considered a scenario where in the simulation we connect two

diagonal nodes or intersections and assumed it as flyover (as assumed in Theorem 3). In this simulation, we connect intersection 1 with intersection 9 and intersection 7 with intersection 3. The simulation is performed and the results for normal scenario (grid scenario) are compared with the above scenario. From Figures 15 and 16, it is observed that the data are transmitted in the shortest path by taking the flyover path. So, flyover communication takes less delay than normal road communication. Here also, as number of vehicles increases, the delay reduces due to high availability of vehicles. GSR also shows high delay than GPSR.

Scenario 3: In this scenario, we have taken two cases: first is single lane simulation and second is multi-lane simulation. From Figures 17 and 18, it is observed that single lane shows less delay as compared to multi-lane. This is because multi-lane has high number of vehicles and a vehicle has more options in selecting the next

Figure 19: Packet delivery ratio comparison for GSR and GPSR.

forwarder node. It is also observed that as number of vehicles increases, the delay decreases. GSR also shows high delay as compared to GPSR routing protocol.

Scenario 4: In the last scenario, we have added a basic error model using path loss model for generating packet error rate and assumed the error happens due to obstacles in the city areas. From Figure 19, it is observed that GPSR shows less packet delivery ratio as compared to GSR. The packet drops due to packet error which is discarded at the destination. As the number of vehicles increases, the links between the vehicles are strong and a vehicle selects the node with good packet delivery ratio, hence it becomes stable.

4 Conclusion

In this paper, we have analyzed the effect of road construction in city-based VANETs. To get a congestion-free traffic, the intersections should be constructed in an intelligent way, so that many vehicles can pass without any communication gap. This enhances the system performance. The flyovers and interchanges should be constructed in a planned way, so that the vehicles can perform communication in order to send data through a shortest path. As vehicles are increasing, the vehicles should use multilane to travel. Moreover, it can transfer the data easily, because of high density of vehicles. As obstacles exist, the vehicles should smartly select the neighboring vehicles so that the packet delivery is high. Simulation results better support the work for evaluating the performance of city-based VANETs. This analysis can help civil works better to construct an intelligent roadway network and design of smart city. This analysis will be a better solution for providing ITSs services to the users.

Conflict of interest: The authors declare that they have no conflict of interest.

Data availability statement: Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

References

- [1] F. Li and Y. Wang, "Routing in vehicular ad hoc networks: a survey," *IEEE Vehi. Technol. Mag.*, vol. 2, no. 2, pp. 12–22, 2007.
- [2] S. Zeadally, R. Hunt, Y.-S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (VANETS): status, results, and challenges," *Telecommun. Syst.*, vol. 50, no. 4, pp. 217–241, 2012.
- [3] C.-Y. Chang, C.-T. Chang, and S.-C. Tu, "Obstacle-free geo-casting protocols for single/multi-destination short message services in ad hoc networks," *Wirel. Netw.*, vol. 9, no. 2, pp. 143–155, 2003.
- [4] X. Zhang, B. Liu, and J. Tang, "A study on the tracking problem in vehicular ad hoc networks," *Int. J. Distrib. Sens. Netw.*, vol. 9, no. 2, p. 809742, 2013.
- [5] L. Wang, S. Zhang, X. Wang, and Y. Zhang, "Research on vehicle automatically tracking mechanism in VANET," *Int. J. Distrib. Sens. Netw.*, vol. 9, no. 8, p. 592129, 2013.
- [6] H. Huang and S. Zhang, "A routing algorithm based on dynamic forecast of vehicle speed and position in vanet," *Int. J. Distrib. Sens. Netw.*, vol. 9, no. 6, p. 390795, 2013.
- [7] H. Zhao and J. Zhu, "Efficient data dissemination in urban VANETs: parked vehicles are natural infrastructures," *Int. J. Distrib. Sens. Netw.*, vol. 8, no. 12, p. 151795, 2012.
- [8] D. Wu, Y. L. Di, H. Zhu, and J. Liang, "The RSU access problem based on evolutionary game theory for VANET," *Int. J. Distrib. Sens. Netw.*, vol. 9, no. 7, p. 143024, 2013.
- [9] U. Nagaraj, M. Kharat, and P. Dhamal, "Study of various routing protocols in VANET," *IJCSST*, vol. 2, no. 4, pp. 45–52, 2011 Oct–Dec.
- [10] S. Gupta, C. Kumar, C. K. Nagpal, and B. Bhushan, "Performance evaluation of MANET in realistic environment," *Int. J. Mod. Educ. Comput. Sci. (IJMECS)*, vol. 4, no. 7, p. 57, 2012.
- [11] Belghith and M. Belhassen, "Routing enhancements in dynamic MANETs with obstacle," In: *Wireless and Mobile Networking Conference (WMNC), 2011 4th Joint IFIP*, IEEE, 2011, pp. 1–5.
- [12] E. Giordano, R. Frank, G. Pau, and M. Gerla, "CORNER: a step towards realistic simulations for VANET," In: *Proceedings of the seventh ACM international workshop on Vehicular InterNetworking*, ACM, 2010, pp. 41–50.
- [13] F. J. Martinez, C.-K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Realistic radio propagation models (RPMs) for VANET simulations," In: *Wireless Communications and Networking Conference, 2009. WCNC 2009. IEEE*, IEEE, 2009, pp. 1–6.
- [14] A. Mahajan, N. Potnis, K. Gopalan, and A. Wang, "Modeling vanet deployment in urban settings," In: *Proceedings of the 10th ACM Symposium on Modeling, analysis, and simulation of wireless and mobile systems*, ACM, 2007, pp. 151–158.
- [15] M. Boban and T. T. V. Vinhoza, "Modeling and simulation of vehicular networks: Towards realistic and efficient models," In: *Mobile ad-hoc networks: Applications*, InTech, 2011.
- [16] H. F. Khazaal, C. Papageorgiou, I. Politis, T. Dagiuklas, and N. Khamiss, "Video over MANETs: the impact of obstacles, node mobility speed and background traffic on the perceived video quality," In: *New Technologies, Mobility and Security (NTMS), 2009 3rd International Conference on*, IEEE, 2009, pp. 1–5.
- [17] Y. Wang, V. Menkovski, I. Wang-Hei Ho, and M. Pechenizkiy, "VANET meets deep learning: the effect of packet loss on the object detection performance," In: *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, IEEE, 2019, pp. 1–5.
- [18] T. Izydorczyk, M. L. T. Fernando, G. Berardinelli, M. Bucur, and P. Mogensen, "Performance evaluation of multi-antenna

- receivers for vehicular communications in live LTE networks,” In: *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, IEEE, 2019, pp. 1–6.
- [19] G. Sun, Y. Zhang, H. Yu, X. Du, and M. Guizani, “Intersection fog-based distributed routing for V2V communication in urban vehicular ad hoc networks,” *IEEE Trans. Intell. Transport. Syst.*, vol. 21, no. 6, pp. 2409–2426, 2019.
- [20] X. Shu, C. Li, W. Chen, J. Yu, and K. Yang, “Performance analysis of V2V radio channel under typical urban intersection scenario,” In: *2018 IEEE International Conference on Communication Systems (ICCS)*, IEEE, 2018, pp. 216–220.
- [21] H. Wymeersch, G. Soatti, M. Nicoli, N. Garcia, B. Denis, and R. Raulefs, “Implicit cooperative positioning in vehicular networks,” *IEEE Trans. Intell. Transport. Syst.*, vol. 19, no. 12, pp. 3964–3980, 2018.
- [22] B. Masini, A. Bazzi, and A. Zanella, “Vehicular visible light networks for urban mobile crowd sensing,” *Sensors*, vol. 18, no. 4, p. 1177, 2018.
- [23] Y. Bi, G. Han, C. Lin, X. Wang, Q. Zhang, and Z. Liu, “Effective packet loss elimination in IP mobility support for vehicular networks,” *IEEE Netw.*, vol. 34, no. 1, pp. 152–158, 2019.
- [24] G. Manzo, M. A. Marsan, and G. A. Rizzo, “Analytical models of floating content in a vehicular urban environment,” *Ad Hoc Netw.*, vol. 88, pp. 65–80, 2019.
- [25] T. Blazek, G. Ghiaasi, C. Backfrieder, G. Ostermayer, and C. F. Mecklenbrauker, “IEEE 802.11 p performance for vehicle-to-everything connectivity in urban interference channels,” *12th European Conference on Antennas and Propagation*, pp. 1–5, 2018.
- [26] F. Lyu, H. Zhu, N. Cheng, H. Zhou, W. Xu, M. Li, et al., “Characterizing urban vehicle-to-vehicle communications for reliable safety applications,” *IEEE Trans. Intell. Transport. Syst.*, vol. 21, no. 6, pp. 2586–2602, 2019.
- [27] C. Tripp-Barba, L. Urquiza-Aguiar, A. Zaldívar-Colado, J. Estrada-Jiménez, J. A. Aguilar-Calderón, and M. A. Igartua, “Comparison of propagation and packet error models in vehicular networks performance,” *Vehi. Commun.*, vol. 12, pp. 1–13, 2018.
- [28] Y. Wang, V. Menkovski, I. W.-H. Ho, and M. Pechenizkiy, “VANET meets deep learning: the effect of packet loss on the object detection performance,” In: *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, IEEE, 2019, pp. 1–5.
- [29] R. S. Raw and D. K. Lobiyal, “B-MFR routing protocol for vehicular ad hoc networks,” In: *Networking and Information Technology (ICNIT), 2010 International Conference on*, IEEE, 2010, pp. 420–423.
- [30] J. Nzouonta, N. Rajgure, G. Wang, and C. Borcea, “VANET routing on city roads using real-time vehicular traffic information,” *Vehi. Technol., IEEE Trans. on*, vol. 58, no. 7, pp. 3609–3626, 2009.
- [31] P. Venkateswaran, R. Ghosh, A. Das, S. K. Sanyal, and R. Nandi, “An obstacle based realistic ad-hoc mobility model for social networks,” *J. Netw.*, vol. 1, no. 2, pp. 37–44, 2006.
- [32] S. A. Aly, T. A. AlGhamdi, M. Salim, H. H. Amin, and A. A. Gutub, “Information gathering schemes for collaborative sensor devices,” *Proc. Comput. Sci.*, vol. 32, pp. 1141–1146, 2014.
- [33] S. Curtis, B. Zafar, A. Gutub, and D. Manocha, “Right of way,” *Vis. Comput.*, vol. 29, no. 12, pp. 1277–1292, 2013.
- [34] S. Kim, S. J. Guy, K. Hillesland, B. Zafar, A. Abdul-Aziz Gutub, and D. Manocha, “Velocity-based modeling of physical interactions in dense crowds,” *Vis. Comput.*, vol. 31, no. 5, pp. 541–555, 2015.
- [35] S. Aly and A. Gutub, “Intelligent recognition system for identifying items and pilgrims,” *NED Univ. J. Res.*, vol. 15, no. 2, pp. 17–23, 2018.
- [36] A. Gutub, “Exploratory data visualization for smart systems,” *Smart Cities*, vol. 3, pp. 1528–1537, 2015.
- [37] S. A. Aly, A. A. Turki, M. Salim, and A. A. Gutub, “Data dissemination and collection algorithms for collaborative sensor devices using dynamic cluster heads,” *Trends Appl. Sci. Res.*, vol. 8, no. 2, p. 55, 2013.
- [38] N. Alharthi and A. Gutub, “Data visualization to explore improving decision-making within Hajj services,” *Sci. Model Res.*, vol. 2, no. 1, pp. 9–18, 2017.
- [39] I. Kaysi, B. Alshalalfah, A. Shalaby, A. Sayegh, M. Sayour, and A. Gutub, “Users’ evaluation of rail systems in mass events: case study in Mecca, Saudi Arabia,” *Transport. Res. Rec.*, vol. 2350, no. 1, pp. 111–118, 2013.
- [40] G. A. Abdul-Aziz and A. ALY, “Trialing a smart face-recognition computer system to recognize lost people visiting the two holy mosques,” *Arab. J. Forensic Sci. Forensic Med. (AJFSFM)*, vol. 1, no. 8, pp. 1120–1132, 2019.
- [41] I. Kaysi, M. Sayour, B. Alshalalfah, and A. Gutub, “Rapid transit service in the unique context of Holy Makkah: assessing the first year of operation during the 2010 pilgrimage season,” *Urban Transp. XVIII Urban Transp. Env. 21st Century*, vol. 18, p. 253, 2012.
- [42] N. Farooqi, A. Gutub, and M. O. Khozium, “Smart community challenges: enabling IoT/M2M technology case study,” *Life Sci. J.*, vol. 16, no. 7, 2019.
- [43] N. AlAssaf, B. AlKazemi, and A. Gutub, “Applicable light-weight cryptography to secure medical data in IoT systems,” *J. Eng. Appl. Sci.*, vol. 2, 2003.
- [44] N. Alassaf, A. Gutub, S. A. Parah, and M. A. Ghamdi, “Enhancing speed of SIMON: A light-weight-cryptographic algorithm for IoT applications,” *Multimed. Tools Appl.*, vol. 78, no. 23, pp. 32633–32657, 2019.
- [45] A. Gutub and F. Al-Shaarani, “Efficient implementation of multi-image secret hiding based on LSB and DWT steganography comparisons,” *Arab. J. Sci. Eng.*, vol. 45, pp. 2631–2644, 2020.
- [46] N. Alassaf and A. Gutub, “Simulating light-weight-cryptography implementation for IOT healthcare data security applications,” *Int. J. E-Health Med. Commun. (IJEHMC)*, vol. 10, no. 4, pp. 1–15, 2019.
- [47] S. K. Bhoi and P. M. Khilar, “Vehicular communication: a survey,” *IET Netw.*, vol. 3, no. 3, pp. 204–217, 2013.
- [48] S. K. Bhoi and P. M. Khilar, “A secure routing protocol for Vehicular Ad Hoc Network to provide ITS services,” In: *2013 International Conference on Communication and Signal Processing*, IEEE, 2013, pp. 1170–1174.
- [49] S. K. Bhoi and P. M. Khilar, “SIR: a secure and intelligent routing protocol for vehicular ad hoc network,” *IET Netw.*, vol. 4, no. 3, pp. 185–194, 2014.
- [50] S. K. Bhoi and P. M. Khilar, “IJS: An intelligent junction selection based routing protocol for VANET to support ITS services,” *Int. Sch. Res. Not.*, vol. 2014, pp. 1–14, 2014.

- [51] S. K. Bhoi and P. M. Khilar, "RVCloud: a routing protocol for vehicular ad hoc network in city environment using cloud computing," *Wirel. Netw.*, vol. 22, no. 4, pp. 1329–1341, 2016.
- [52] S. K. Bhoi, P. M. Khilar, and M. Singh, "A path selection based routing protocol for urban vehicular ad hoc network (UVAN) environment," *Wirel. Netw.*, vol. 23, no. 2, pp. 311–322, 2017.
- [53] S. K. Bhoi and P. M. Khilar, "A road selection based routing protocol for vehicular ad hoc network," *Wirel. Personal Commun.*, vol. 83, no. 4, pp. 2463–2483, 2015.
- [54] S. K. Bhoi and P. M. Khilar, "VehiHealth: an emergency routing protocol for vehicular Ad Hoc network to support healthcare system," *J. Med. Syst.*, vol. 40, no. 3, p. 65, 2016.
- [55] S. K. Bhoi, P. M. Khilar, M. Singh, R. R. Sahoo, and R. R. Swain, "A routing protocol for urban vehicular ad hoc networks to support non-safety applications," *Digital Commun. Netw.*, vol. 4, no. 3, pp. 189–199, 2018.
- [56] S. K. Bhoi, S. K. Panda, S. R. Ray, R. K. Sethy, V. K. Sahoo, B. P. Sahu, et al., "TSP-HVC: A novel task scheduling policy for heterogeneous vehicular cloud environment," *Int. J. Inf. Technol.*, vol. 11, no. 4, pp. 853–858, 2019.
- [57] S. K. Bhoi, D. Puthal, P. Mohan Khilar, J. J., p. C. Rodrigues, S. K. Panda, and L. T. Yang, "Adaptive routing protocol for urban vehicular networks to support sellers and buyers on wheels," *Comput. Netw.*, vol. 142, pp. 168–178, 2018.
- [58] S. K. Bhoi, P. K. Sahu, M. Singh, P. Mohan Khilar, R. R. Sahoo, and R. R. Swain, "Local traffic aware unicast routing scheme for connected car system," *IEEE Trans. Intell. Transport. Syst.*, vol. 21, pp. 2360–2375, 2019.
- [59] S. K. Bhoi, C. Mallick, M. Singh, and S. K. Panda, "High CO_2 zone localization in city areas using hardware implementation of urban vehicular ad hoc network (UVANET) platform," *Int. J. Inf. Technol.*, vol. 12, no. 1, pp. 65–70, 2020.
- [60] A. Varga and R. Hornig, "An overview of the OMNeT++ simulation environment," In: *Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops*, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2008, p. 60.
- [61] A. Varga, "OMNeT++," *Modeling and tools for network simulation*, Berlin, Heidelberg, Springer, 2010, pp. 35–59.