A Modified On-Demand Vector Distance Routing Protocol Incorporating Alternate Vehicle-RSU-Vehicle and Vehicle-RSU- RSU Paths

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The Vehicular ad-hoc network (VANET) is an ad-hoc wireless network that allows moving or stationary vehicles to communicate with each other and with the roadside to facilitate various applications, including safety, collision avoidance, and traffic monitoring. The routing protocols provide vehicle-to-vehicle and vehicle-to-roadside communication for the VANET. However, due to the rapid mobility of the vehicles in the network, these protocols suffer from broken links, which leads to unreachable transmission. This paper proposes a new routing protocol based on the ad-hoc on-demand distance vector (AODV) routing protocol to locate the optimal routing of packets in moving vehicles by constructing alternative stable paths with the roadside unit. In the case of broken links, alternative paths can be used for message transmission, reducing packet discarding. The proposed protocol was simulated, and the results were compared with the original AODV. According to the obtained results, the proposed protocol improves the performance of the AODV in terms of throughput, end-to-end delay, and delivery ratio.

Povzetek: Predlagana je nova metoda oz. protokol za Vanet, omrežje za vozila. Primerjava pokaže izboljšave glede na AODV.

1 Introduction

The Mobile Ad Hoc Network (MANET) is a decentralized wireless network that enables communication between mobile nodes with self-configuration and self-adaption. The freely moving nodes in MANET communicate while providing routing services to other nodes in the network. The Vehicular Ad Hoc Network (VANET) is an instance of MANET that allows moving or stationary vehicles to communicate with each other and the roadside. VANET provides autonomous communication for connected vehicles to facilitate various applications, including safety, collision avoidance, and traffic monitoring. Three types of communication facilitate these applications. These are vehicle-to-vehicle, vehicle-to-roadside communications, and hybrid communication. Various routing protocols are proposed and used to control such communications based on geographical or topological routing, as illustrated in Figure 1 [23].

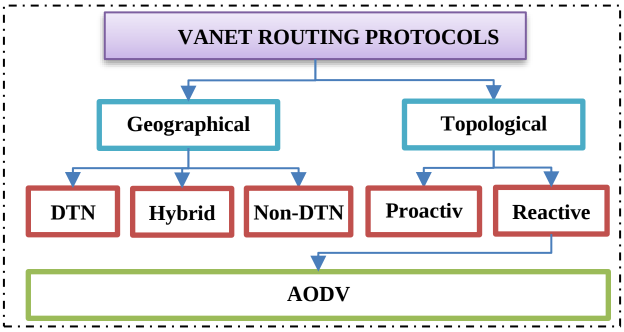

Figure 1: Classification of routing protocol in VANET.

In the geographical routing protocols, the communication path is determined by the position of both the destination and the neighboring nodes. The neighboring nodes are those located within the radio range of the communicating nodes. Accordingly, rather than using network addresses, communications between nodes are established through their geographical locations, determined using the Geographic Position System (GPS). The source node stores the destination's position in the packet header, enabling packet forwarding without prior route discovery or maintenance. The next-node is selected using a greedy approach with no prior assumption about the path to be followed. This operation is repeated until the transmitted packet reaches the destination node. Geographical routing protocols ensure path stability from one node to another [8]. However, the problem with geographical routing protocols is the inability to locate the next-node in many cases because the location of the destination vehicle cannot be determined in advance. The delay tolerance network (DTN) protocol, one of the well-known geographical routing protocols, stores forwarding information but not the entire path between the source and the destination. A delay is encountered if no neighborhood nodes are found to be used for packet forwarding. In such a case, the packet is stored until nodes are located in the neighborhood. Hence, the name DTN is given. While in the non-DTN, communication fails if no neighborhood nodes are found to be used for packet forwarding. Non-DTN depends on re-transmitting packets to avoid delays that may be faced due to the absence of a neighborhood within the range. Finally, based on the case, the hybrid protocol mixes packet storage and re-transmission [20].

The topology protocols are categorized into reactive and proactive routing, depending on the network topology. Routing is implemented in proactive mode using the shortest pre-assigned paths. The routing information is stored in a table-like format, updated, and exchanged among connected nodes whenever the network topology changes. Due to the nature of the proactive protocols, paths are maintained regardless of whether they are in use or not. Accordingly, unused paths occupy a significant portion of the available bandwidth [13]. However, the connection between the communicated nodes would not be constant due to the dynamic nature of these networks. In many cases, some packets will not be transmitted by a specific node in the path due to the unavailability of the neighboring nodes, and the packets will be discarded. These discarded packets harm the performance of the VANET as the source node is required to restart the route discovery procedure and re-transmit the discarded packets [6]. On the other hand, the reactive routing protocol does not store the routing information if no communication is conducted throughout the path. The path discovery is only implemented when a node needs to communicate with another, resulting in a high route discovery delay in reactive protocols. There are many types of reactive routing protocols, such as link-state routing (OLSR), Temporally Ordered Routing Algorithm (TORA), Dynamic Source Routing (DSR), and Ad Hoc On-demand Distance Vector (AODV) [9].

AODV is a simple, reactive, and on-demand routing protocol that is reliable and efficient. AODV requires less overhead as compared to proactive routing protocols. AODV is implemented in three stages: the route discovery stage, the generation of the message, and route maintenance. A distinguishing feature of the AODV is the utilization of the sequence number. The routing table at each node contains three fields, the next-hop node, a hop count, and the sequence number, which is a time-stamped indication of the quality of the path. AODV is operated using a request-response cycle, as illustrated in Figure 2. An RREQ message, which represents a request message, is broadcast from the node to discover a route to a destination. A node receiving such an RREQ message might also broadcast this request if it has no route to the destination. An *RREP* message is sent back to the source node by the destination or a node with a route to the destination. These messages are formed in a request-response cycle to route discovery. The *RREP* message is unicast in reverse route to the source node, which creates a bidirectional route between the source and the destination [22]. Accordingly, AODV provides updated path information and reduces the memory space required by other protocols for path maintenance and response to path failure accordingly. However, AODV suffers from delays, which result from its reactive nature and the inconsistent path due to nodes' outdated information. The main problems with AODV are the broken links and packet discarding, which reduce the overall performance of this protocol [5].

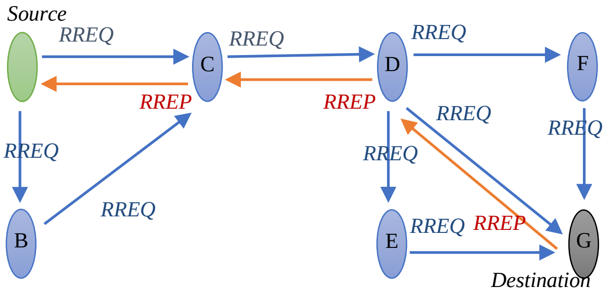

Figure 2: AODV Request-Response cycle.

Generally, a significant feature of the VANET is the rapid topology changes due to high vehicle mobility, which makes the routing process challenging. Touting protocols inherited from the MANET networks, such as DSR, OLSR, and AODV, showed poor performance in VANET [3]. The problem with these protocols is the broken link due to topology changes that cause routing instability. Overall, such a problem degrades the performance of these protocols as many packets are discarded, delayed, and the network is overloaded due to packet re-transmission. This paper establishes an alternative path to provide stability to the source-destination connection and avoid broken links. An alternative path is created between vehicles and the RSU. This alternative path is utilized in case the main path is lost. Thus, avoid broken links.

2 Previous work

AODV has been continuously extended by incorporating information and altering the process of route discovery and route maintenance to improve the throughput, packet loss, and communication overhead. Accordingly, Abedi, Fathy [1] proposed improving the route discovery stage using the direction information at each node for selecting the next-hop (next-node). The proposed protocol uses two parameters: the direction and the position for next-hop selecting during the route discovery stage. The results showed that the utilized information improved the performance of the AODV and reduced the network overhead in different traffic situations compared to the original AODV. Wang, Yang [26] used fuzzy logic to improve the delay and packet discarding in the route discovery stage. A fuzzy logic model is used with the estimated route lifetime and the directional vehicles to select the next hop.

Similarly, Ding, Chen [10] improved the route discovery using the speed and direction of the moving vehicles obtained from the GPS to decrease overhead and enhance route stability. The optimized route discovery stage reduces the number of broken links and improves the routing stability. Sun, Chen [24] proposed a GPS-based AODV routing protocol to establish a route between the source and the destination nodes. The GPS location constrains the flooding of AODV routing packets to improve routing performance. Accordingly, such constraints reduce the network overhead compared to the original AODV. As a result, the number of broken links and the packet discarding ratio is reduced, and the average end-to-end delay is also reduced. However, when they considered different highway scenarios, the performance of the constrained-AODV in terms of packet loss was not satisfactory (more than 10%).

Yu, Guo [27] improved the reliability of routing protocols using vehicle movement information. The expiry time of the route path is estimated based on the vehicles' movements and the route's weight. Although the estimated time and route weight reduced the network load, the packet discarding ratio was not improved. Aswathy and Tripti [7] provide stable clusters and implement routing by gateway nodes and cluster heads. The results proved that the improved protocol reduces the overhead, and the efficiency can be improved. Keshavarz, Noor [15] used route status checking by continuously updating routing flags saved in the Routing Table Flag (RTF) to avoid unnecessary broadcasting. This modification improves the loss and decreases the packet discarding ratio, according to the results. Saha, Roy [21] modified the AODV routing protocol based on using a queue constructed based on the IPs of the nodes that have been conveyed in the delivery of the packets to the node possessing. In the event of a link breakage, the intermediate node unicasts the received packet to the queue-saved nodes instead of discarding it. The results showed that the modified AODV reduces packet discarding and imposes minor overhead compared to the original AODV protocol. However, such a mechanism cannot be applied in an urban environment, where the queue will not be able to be populated as efficiently as in the city environment.

Raju and Parikh [19] avoided message discarding, reducing the average end-to-end delay by integrating DSR with the AODV. He, Xu [14] used the vehicle movement and channel condition information in the route discovery stage. Feyzi and Sattari-Naeini [12] used vehicle direction, speed, and distance for route discovery as inputs to a fuzzy logic model, which reduced the packet discarding ratio. Yet, the end-to-end delay has increased significantly due to the utilization of the fuzzy-logic model. Wang, Shan [25] used the prediction of the vehicle distances based on the vehicle movement for router discovery. Yet, the throughput of the developed protocol was poor. Moussaoui, Djahel [17] incorporate the location of the destination and only enable packet podcasting towards the location of the destination. The aim is to reduce the network overhead by reducing the amount of message podcasting.

Mubarek, Aliesawi [18] proposed reducing the network overhead by incorporating location and distance information for next-hop discovery. The results proved that the proposed protocol was efficient in improving the performance of a VANET. Zhang, Xiao [28] proposed a new route discovery stage by mining the historical vehicle trajectory data as proof of social intimacy. The results showed that such a modification improves delay and reduces packet discarding. Al-Shabi [4] proposed using a tree-structure-like representation of the nodes for message transmission in multi-casting to improve the delay and delivery ratio. Yet, such an approach increases the overhead significantly. Ahamed and Vakilzadian [2] extended the work of Abedi, Fathy [1] by selecting the next-hop using the speed, direction, and position of vehicles. Ebadinezhad [11] proposed to hop clustering to simplify routing and ensure a better quality of service. The results proved that the proposed protocol enhanced the overall delivery ratio, throughput with minor delays, and less routing load than the original AODV.

Malik and Sahu [16] evaluated AODV and DSR performance for VANETs. According to the results, DSR outperformed AODV in packet delivery ratio, packet loss, overhead, and average end-to-end delay. A comprehensive study of the various routing protocols in VANETs is described and presented by Raju and Parikh [19] to provide designers and researchers with an effective comparison and better analysis. Table 1 summarizes the related work discussed in this section.

Table 1: AODV modification techniques.

Ref.	**Technique**	**Goal**
Abedi, Fathy [1]	Using location in the route discovery stage	Reduce overhead
Wang, Yang [26]	Using time and speed information in the route discovery stage	Reduce overhead
Ding, Chen [10]	Using speed and direction information in the route discovery stage	Improve stability
Sun, Chen [24]	Using location and direction information in the route discovery stage	Improve stability
Yu, Guo [27]	Using location and direction information in the route discovery stage	Improve stability
Aswathy and Tripti [7]	Implementing routing by gateway nodes and cluster heads	Reduce overhead
Keshavarz, Noor [15]	Using an up-to-date routing flag in the route discovery stage	Improve stability
Saha, Roy [21]	Building queue to be used for packet unicast in link breakage case	Reduce discarding
Raju and Parikh [19]	Integrating dynamic source routing with AODV	Improve stability
He, Xu [14]	Using location information in the route discovery stage	Improve stability
[12]	Using direction, speed, and distance of vehicles in the route discovery stage with a fuzzy logic model	Reduce discarding
Wang, Shan [25]	Prediction of the distances between nodes in the route discovery stage	Reduce discarding
Moussaoui, Djahel [17]	Using the location of the destination in the route discovery stage	Reduce overhead
Mubarek, Aliesawi [18]	Using location and distance in the route discovery stage	Reduce overhead
Zhang, Xiao [28]	Using historical trajectory in the route discovery stage	Reduce overhead
Al-Shabi [4]	Using message multi-casting in the message transmission stage	Reduce discarding
Ahamed and Vakilzadian [2]	Using direction, speed, and distance in the route discovery stage	Reduce overhead
Ebadinezhad [11]	Using hop clustering to simplify routing	Reduce discarding

3 Proposed work

The AODV protocol depends on the packet transmission based on the route discovered in the request-respond cycle. An RREQ message is propagated to find a path or alternative path in case of broken links. An alternative path is generated when RERR is received. In most cases, as the vehicles are moving, the message will be discarded due to the broken link, as no alternative path can be found in such a case. The proposed solution maintains an alternative path by linking the nodes with the nearest RSU. Each RSU is given an ID, stored and updated for each vehicle. Besides, the RSU maintains each vehicle's location, direction, and speed to locate an alternative path when required. As a broken link is encountered, an alternative path can be generated using vehicle-RSU-vehicle transmission or vehicle-RSU-RSU transmission, as illustrated in Figure 3 and Figure 4, respectively. In normal cases, when no broken links are encountered, the RSU is working as the granted party for the communicated vehicle. Accordingly, each vehicle used the ID of the granted RSU, which can be used by other vehicles or other RSUs if the vehicle causes the broken links. As such, the flow chart of the proposed protocol is given in Figure 5.

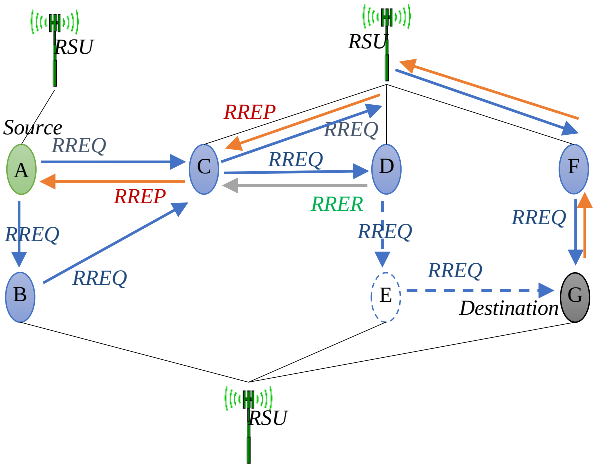

Figure 3: Alternative Vehicle-RSU-Vehicle path AODV Request-Response cycle

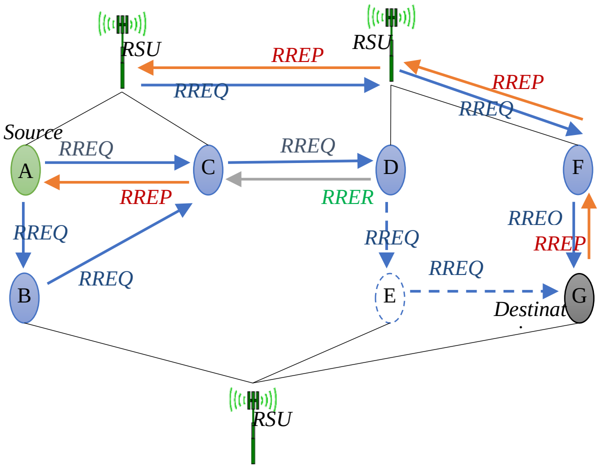

Figure 4: Alternative Vehicle-RSU-RSU Path AODV Request-Response cycle.

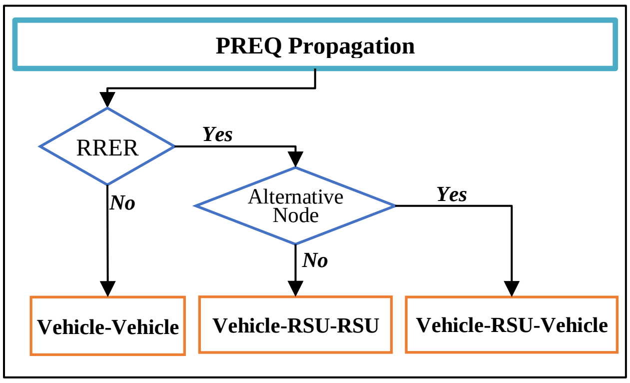

Figure 5: Flowchart of the proposed AODV-based protocol.

The proposed solution maintains a table at each node that contains four fields: the next-hop node, a hop count, the sequence number, and the nearest RSU ID, which is continuously updated as the vehicle is moving. The RSU stores the connected vehicles' location, direction, and speed information. This information and fields are utilized to create and maintain a path for moving vehicles in the VANET network. Accordingly, three scenarios are implemented in the proposed protocol depending on the topology of the network and the availability of the vehicle connections to the nearest RSU. These scenarios are described in the following.

3.1 First Scenario: vehicles-based path

The proposed solution uses the request-response cycle to discover a route to a destination by propagating RREQ messages, which represent request messages, from the source node to the next-hop iteratively. The route is discovered when the destination or a node with a route to the destination sends the *RREP* message back to the source node. Each node then stores information about the route in the routing table. This information is used to forward the packets from the source to the destination. These processes are implemented exactly as followed by the original AODV.

3.2 Second Scenario: vehicle-RSU-vehicle path

When a node receives an RRER message due to broken links in the discovery or the maintenance stages, an RREQ message is sent to the associated RSU with the ID saved in the routing table. The RSU, in turn, responds with the alternative node to be used to complete the communication cycle. As a result, a new alternative path is established for the same source-destination communication. The *RREP* message is unicast to the alternative vehicle, which broadcasts the RREQ message into the next-hops. The RREP is unicast in reverse route to the source node, which creates the alternative path. The communication between the vehicle and the RSU is established using the AODV protocol. Accordingly, AODV provides updated path information.

3.3 Third Scenario: vehicle-RSU-RSU path

In another scenario, when a node receives an RRER message due to broken links in the discovery or maintenance stages, an RREQ message is sent to the associated RSU with the ID saved in the routing table. The RSU, in turn, responds with an RREP message when no alternative vehicle is available. This case is significant, especially in urban areas where vehicles might not be within the range of each other all the time. Then the RSU sends an RREQ message to the nearest RSU, and the request-response process is established by RSU-to-RSU communication. The next RSU locates the next hop by first exploring the available vehicle. If no vehicle is available, the next RSU is communicated to be the next node. Accordingly, a new alternative path is established for the same source-destination communication.

Accordingly, maintaining the RSU of each node in the routing table and maintaining the vehicles' ID in the RSU table ensures that there are always at least two alternate paths to be used in case of a broken link. The proposed protocol provides a flexible connection between the communicated vehicles. Yet, to reduce the packet discarding, extra communication might be required. However, this communication overhead is less than the overhead required in the case of a broken link, as message re-broadcasting is not necessary to find a new path. Instead of the moved away nodes, an alternative path with common nodes with the original path is established with RSU involvement.

4 The simulation results

The proposed protocol is simulated using the NS-2 simulator with predetermined parameters, as listed in Table 2. The simulation is executed over a simulated wireless channel and M-Grid mobility with a duration of 300 seconds, in which 1 packet is sent every second. Various numbers of vehicles and vehicle speeds were simulated to extract reliable results. The results are measured in delivery percentage, as the number of received packets divided by the total number of sent packets. Besides, end-to-end delay is measured, and the communication overhead is also measured as the total number of RREQ and RREP messages between the communication nodes. The evaluation metrics are listed in Table 3.

Table 2: The simulation parameters.

Parameter	Value
Simulation Time	300 seconds
Map Size	2000 m × 2000 m
Vehicles speed	20 ,40, 60, 80 KM/H
Number of vehicles	50, 100, 150, 200, 250
Number of RSU	5, 10, 15, 20, 25
Transmission Range	250 m
Packet sending rate	1 packet/second (128 kb)

Table 3: The evaluation metrics.

Metric	Calculation
Delivery Ratio (%)	$\mathrm{DR} = \#RecivedPackets/\#SentPackets$
End-to-End Delay (second)	Time to deliver the data packet
Throughput (kbps)	Average data packets delivery per second
Overhead (%)	$\mathrm{Overhead} = (\#RREQ - \#Nodes)/\#Nodes$

Figure 6 illustrates the packet delivery ratio at different node densities with a vehicle speed of 20km for the proposed protocol and the original AODV. The packet delivery ratio is significantly higher than the AODV, especially in low-density nodes, which may reflect the situation of the urban areas. This is due to the utilization of the alternative path created with the support of the RSUs. As noted, in high-density situations, both protocols perform well. Figure 7 illustrates the packet delivery ratio at different vehicle speeds with a high-density situation of 250 vehicles. As the vehicle speed increases, the probability of broken links increases, which results in a reduction in the packet delivery of the original AODV. The packet delivery ratio is much higher for the proposed protocol due to the alternative path techniques. Figure 8 illustrates the end-to-end delay at different node densities with a vehicle speed of 20 km/h for the proposed protocol and the original AODV. In contrast, Figure 9 illustrates the end-to-end delay comparison at different vehicle speeds with a high vehicle density situation of 250 vehicles. The throughput and overhead of the original AODV and the proposed protocol are illustrated in Table 4 and Table 5.

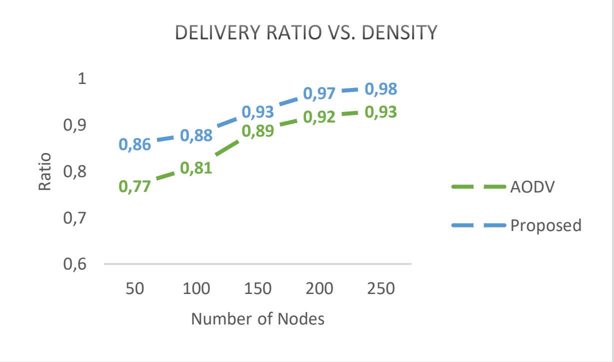

Figure 6: Delivery ratio comparison with various number of nodes.

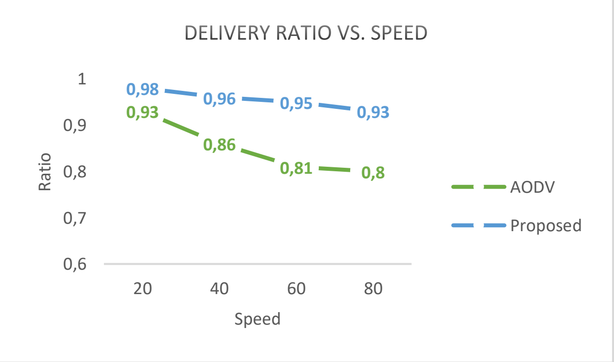

Figure 7: Delivery ratio comparison with various cars' speed.

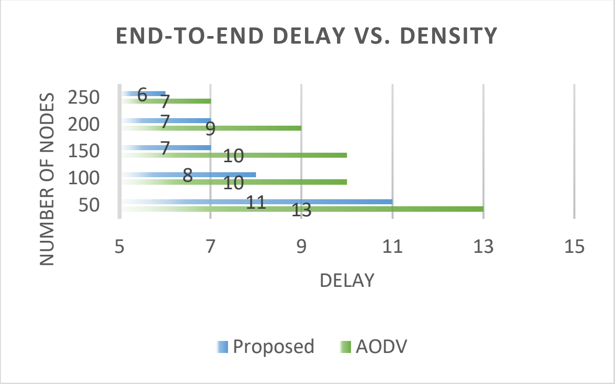

Figure 8: End-to-End delay comparison with various numbers of nodes.

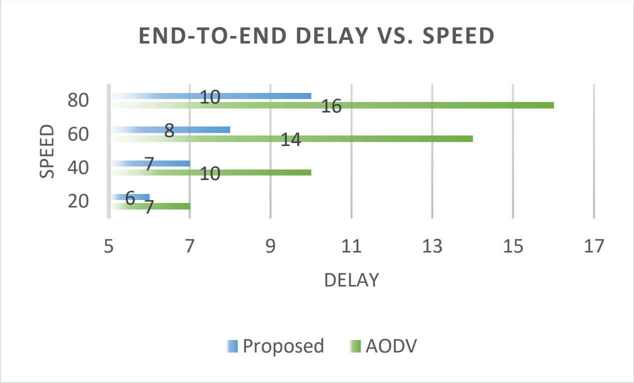

Figure 9: End-to-End delay comparison with various cars' speed.

Table 4: Throughput of the AODV vs. proposed solution.

Routing Protocols	Avg. Throughput (kbps)	Sim. Time	# Vehicles	Speed
AODV	11.55	300	250	20
Proposed	15.22			

Table 5: Overhead of the AODV vs. proposed solution.

Routing Protocols	Avg. Overhead (%)	Sim. Time	# Vehicles	Speed
AODV	84	300	250	20
Proposed	86			

The results show that the delivery ratio increases when the number of cars increases. The performance of the proposed solution in low-density situations or high-speed cars, which might represent the highway situation, is much better than the AODV. The throughput and the delay are also improved using the proposed alternative paths. However, as noted, the overhead using the proposed solution increased slightly compared to the AODV.

5 Discussion

As presented in the results, compared to the original AODV, the proposed method reduces the dropping rate, increases the throughout, and does not increase the overhead significantly. Similar to the work by Abedi, Fathy [1], Wang, Yang [26], Ding, Chen [10] and Sun, Chen [24] decrease overhead and enhance route stability. Yet, it does not suffer from low throughput in highway scenarios, as reported by Ding, Chen [10], and Sun, Chen [24]. The improvement in the throughput is due to the flexibility added by the alternative paths utilized by the proposed method. Besides, the proposed method does not overload the network in the route discovery process as implemented by Mubarek, Aliesawi [18], Zhang, Xiao [28], Al-Shabi [4], Ahamed and Vakilzadian [2], and Ebadinezhad [11].

6 Conclusions

This paper proposed a modified solution to the AODV protocol for VANET networks. The proposed solution is to maintain alternative paths between the nodes by linking the nodes with the nearest RSU. As long as a broken link is encountered, the alternative path can be generated using vehicle-RSU-vehicle transmission or vehicle-RSU-RSU transmission. In normal cases, when no broken links are encountered, the RSU is working as the granted party for the communicated vehicle. The proposed protocol is simulated using the NS-2 simulator. The simulation is executed over a simulated wireless channel and M-Grid mobility with a duration of 300 seconds, in which 1 packet is sent every second. Various numbers of vehicles and vehicle speeds were simulated to extract reliable results. The results showed that the delivery ratio increases when the number of cars increases. The performance of the proposed solution in low-density situations or high-speed cars, which might represent the highway situation, is much better than the AODV. The throughput and the delay are also improved using the proposed alternative paths. However, as noted, the overhead using the proposed solution increased slightly compared to the AODV.

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