Performance Evaluation and Discrimination of AODV and AOMDV VANET Routing Protocols Based on RRSE Technique

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Abstract
The routing protocol is an applied standard to determine the communication schemes of different entities with each other to transfer and process the desired data in considerable time via the best routes from the source to the destination. This paper presents the performance evaluation and discrimination for various parameters of two different routing protocols using the Root Relative Squared Error (RRSE). The two protocols under study are Ad-hoc On-demand Distance Vector (AODV) and Ad-hoc On-demand Multipath Distance Vector (AOMDV). The literature review reveals the simulation results of a number of nodes that varies approximately between 5 and 450 nodes. Therefore, that the simulation results will be analyzed for two different experiments as follows: the first, the effect of initial node energy variation between 50 and 100 J at a fixed network size. Whereas in the second, it reveals the impact of the network size, which varies between 50 and 450 nodes at constant initial node energy which is tested between 50 and 100 J. The obtained results of the selected parameters prove that the AOMDV protocol is more efficient, robust, and reliable than the AODV protocol for the first experiment, while the RRSE values of AODV are better for the second. Moreover, the proposed technique based on the RRSE algorithm is advantageous for comparing the two routing protocols.

Keywords VANET · Throughput · Packet delivery ratio · Average end to end delay · AODV · AOMDV

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1 Introduction

Ad-hoc is a Latin phrase that means “for this special purpose” [1]. It is a special type of local area network (LAN), with an infrastructure-less network that coordinates the flow of messages between vehicles (V2V) communication and communication between roadside infrastructure units (RSUs) (V2I) [2]. The possibility of the exchange of data between vehicles over an ad-hoc network environment is called a Vehicular Ad-Hoc Network (VANET). VANET is a sub-class of the Mobile Ad-Hoc Network (MANET) that uses radio-frequency channels as its physical medium, where the vehicles are used instead of mobile nodes. The nodes are moving separately in any direction, so that the network topology is changing continuously.

VANET is an urgent need to cut back the carbon emissions and environmental pollution by emitting fewer gases, mitigating road incidents, conserving energy, and relieving congestion [3]. It helps vehicle drivers to communicate and to coordinate among themselves in order to improve traffic safety by transmitting information to drivers and concerned authorities [4], transportation efficiency, and to avoid any critical situation through V2V communication (e.g. road accidents, traffic jams, over-speeding, free passage of emergency vehicles and unseen obstacles,…etc.) [4].

The routing protocol is a standard that specifies how different entities communicate with each other in the shortest path to transfer the desired information in considerable time via the best routes from the source vehicle to the destination. The VANET routing protocols are classified as follows: routing protocol based on Position-Based, Topology, Broadcast, Cluster, and Geo-cast [5]. This paper concentrates on topology-based routing protocols. In VANETs, the term “topology routing” refers to finding the shortest path between source and destination nodes [6]. It is divided into proactive, reactive, or hybrid routing protocols [7]. In the proactive routing protocols, each node in the network uses a routing table, which maintained and updated periodically to identify the next hop towards the destination as well as all hop counts for the destinations [8 , 9], regardless of network load, bandwidth constraints, or network size. In the reactive routing protocols, the source nodes search on-demand for the routes to the destination and then create the connection to transmit and receive the packets. The hybrid routing protocols utilize the capabilities of both reactive and proactive protocols and unite them together to achieve better results [4].

In this paper, two different routing protocols will be evaluated and discriminated, the Ad-hoc On-demand Distance Vector (AODV) protocol, and the Ad-hoc On-demand Multipath Distance Vector (AOMDV) protocol, based on the Root Relative Squared Error (RRSE) technique, with the same simulation parameters. The selected parameters of performance evaluation are sent packets (SP), Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Average End-to-End delay (AETED), and an Average Through-Put (ATP). In this study, two different scenarios are presented: the first scenario, the effect of changing the initial node energy ranges between 50 and 100 J at a fixed network size, which is selected between 50 and 450 nodes. The second scenario offers the impact of varying the network size between 50 and 450 nodes at constant initial node energy, which is pre-determined between 50 and 100 J.
2 Literature Review

There are many papers developed for evaluating the performance of various routing protocols such as AODV, AOMDV, CBF, ASTAR, and GPCR, DSDV, GPSR, OLSR, and GPCR. In [10], five routing protocols (AODV, DSDV, GPSR, OLSR, and GPCR) were simulated. The simulation results revealed that OLSR was the best in terms of throughput and PDR. In contrast, the GPSR and GPCR were confirmed to be more efficient in the event of overhead and latency. The paper [11] presented the results of a performance investigation for three protocols (AODV, DSR, and DSDV) in different environments (Real-world, Highway Scenario, and Manhattan Grid) with variation in density of vehicles. When compared to AODV and DSDV, DSR performance is found to be more efficient in terms of throughput and latency. The DSR showed maximum throughput for the scenarios of real-world and Manhattan grid, whereas its performance vanished in the case of the highway. In this case study, the AODV performed efficiently with respect to the DSDV in terms of throughput. The latency for DSR in all scenarios is the minimum, whereas the AODV verified the maximum latency for the real world and the grid scenarios.

The paper [12] developed the mobility model of DSDV based on speed node variation. The results proved that as the node speed increased, both PDR and throughput gave poor performance. In [13], the comparison of eight VANET protocols (AODV, DSR, FSR, DSDV, OLSR, ZRP, GPSR, and DYMO) for the parameters (PDR, latency, throughput, and the routing cost as performance metrics) in an urban environment using realistic node mobility. The results showed that the geographic routing protocols performed better than the rest of the protocols, as this type of protocol uses the information of the node’s position proving, it suitable for this kind of network. In [14], the performance of (AODV, OLSR, and DSDV) was compared in the cases of low-density, low speed scenario an increase in the density or speed of nodes. The results displayed that DSDV and OLSR performed better than AODV. The analysis of the produced results concluded that OLSR outperformed better than the other two protocols in the event of increasing the density or speed of nodes. The three routing protocols (AODV, DSR, and DYMO) were evaluated in [15]. It was noticed that in the case of latency, the AODV has better performance than others do. The DYMO has low latency and large throughput, so it is better than the other two protocols. In [16], the simulation results were performed using AODV and MAODV in terms of PDR. The obtained results confirmed that the MAODV had performed more efficiently than the AODV. The performance parameters (throughput, packet loss, latency, and PDR) are estimated in [17] for the routing protocols AODV, AOMDV, and DSDV. The produced results showed that AOMDV outperforms AODV and DSDV for packet loss and PDR. In spite of this, AODV throughput was more efficient than that of AOMDV and DSDV. Moreover, the results confirmed that DSDV performance is better than AODV and AOMDV in terms of latency.

The paper [18] evaluated the performance of (AODV, OLSR, and DSDV) in terms of (PDR, Packet Loss Ratio “PLR”, AE2ED, jitter delay, number of packets sent and received, and ATP) for a network size of 50 vehicles. The AE2ED of DSDV outperforms OLSR and DSDV. AODV shows improved performance compared to OLSR and DSDV protocols in both the number of packets sent and received. The PDR results
show that the AODV is more reliable than others in over-dense traffic networks, so it is a practical routing application. The DSDV protocol shows the highest PLR, while it is the lowest for the AODV protocol. AODV shows an improvement in efficiency compared to OLSR and DSDV protocols, which require minimal jitter delay. AODV achieved the highest throughput among the three routing protocols considered.

In the paper [19], the methodology of statistical design of experiments (DOE) is presented because there are no previously applied different DOE methods together to evaluate and the model routing protocol performance of VANET protocols. It compared the results of three applied experimental design methods, namely the full two-level factorial method, the Plackett–Burman method, and the Taguchi method. It studied four factors (node density, number of connections, black hole and wormhole attacks). It generated the fit of the regression models by using measures of R-squared fit and a graph of the fit of the measured responses to the AODV protocol predicted responses (PLR, AE2ED, and NRL), then performed analysis of variance (ANOVA) to explore statistical significance and compare the percentage contribution of each coefficient. The Network Simulator (NS-3) and Urban Mobility Simulator (SUMO) are used to implement the VANET simulation.

3 Topology BASED ROUTING PROTOCOLS

The topology-based routing protocols are classified as (reactive, proactive, and hybrid). This paper concentrates on reactive routing protocol. That protocol has two phases, as follows:

- **Route discovery** the source vehicle issues a route discovery broadcast packets within the network to exchange data when there is a demand if the route towards the destination is not included in the current source vehicle routing table.
- **Route maintenance** it is required when the route is broken. It is due to the continuous links’ failure within the established route. The confirmation of a correctly received packet is done by the backward route.

The paper presents a simulation of two reactive based routing protocols: AODV and AOMDV. They are briefly described as follows:

3.1 Ad-hoc On-Demand Distance Vector (AODV) Protocol

AODV minimizes the number of required broadcasts by creating routes on demand. When a route to a specific destination is needed, the source node broadcasts a Route REQuest message (RREQ) to its neighbors. Each request has a sequence number to eliminate the possibility of forwarding the same packet more than once. Information with a higher serial number represents a more correct and fresh value [7]. When the destination node receives the request, it sends back a Route REPLY message (RREP) to the source node, through a temporary path to it. Both route requests and route replies
are responsible for the route discovery phase. Then update the entries in the node routing table, with only the next hop. The unused routing table entities are removed after a period of time [20]. If a link fails, then a Rout ER Ror (RERR) message is passed back to the source that contains a list of all nodes that are affected by link failure [21]. When the source node receives it, it can reinitiate route discovery again [22].

### 3.2 Ad-hoc On-Demand Multipath Distance Vector (AOMDV)

It is an extension of the AODV routing protocol, which is an on-demand multipath decision-making protocol. It discovers multipath between the source and destination in a single route discovery. The paths are computed and guaranteed to be loop-free and disjointed. This protocol uses alternative paths to reach the destination when all other routes fail. It avoids the possibility of congestion and increases reliability. On the other side, it increases the network overhead in the discovery phase [8]. The protocol has extra RREP and RERR for multipath discovery and maintenance along with extra fields in routing control packets. It has a loop-free and disjointed path so that each node needs to follow two rules [23]: First, for the same destination sequence number, nodes never advertise a route shorter than the one already advertised. The advertised hop-count is defined in [6] as the maximum hop-count of the multiple paths for destination available to the source node. Second, nodes never accept a route longer than one already advertised. It keeps up connectivity and provides a fast and useful approach for recovering errors. On the other hand, it has more message overheads during new path discovery because of grown-up steeping since it is a multipath routing protocol [7], 9.

### 4 Simulation Setup and Parameters

#### 4.1 Simulation Setup

NS-2 is an open-source discrete event-driven simulator designed specifically for research in computer communication networks [20]. The network simulator tool (NS-2 version 2.34) is based on a virtual machine that uses the Ubuntu operating system release 16.04 with an Intel Xeon processor and 48 GB of RAM. NS-2 utilizes Network Scenario Generator version 2.1 (NSG 2.1). NSG is a TCL script generator tool, which generates TCL (.tcl) scripts automatically. When running it, a new format of trace file (.tr) will be generated. The Network Animator (NAM) tool visualizes the movement of the vehicles. To read the output trace file and to evaluate the performance results, the (.awk) scripts are used. In this paper, the performance of AODV and AOMDV is evaluated with a number of connection counts of 50% of the network size within the simulation area of two km² during a time of 100 s. The simulation parameters are listed in Table 1.

The simulation results are evaluated in two experiments as follows:

1. The effect of initial node energy changes at a certain network size.
2. The effect of network density changes at a certain initial node energy.
4.2 Performance Parameters

In this study, the performance is measured using the following five parameters: Sent Packets (SP), Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Average End-to-End Delay (AETED), and Average Throughput (ATP). These parameters are defined as follows:

1. Sent Packets (SP): It is the total number of packets sent from any source node through the network in a particular time interval.

2. Packet Delivery Ratio (PDR): It is the ratio of total data packets received at the destination to the total data packets sent from the source nodes [24]. This parameter is useful for measuring the reliability and capacity of the tested routing protocol. The PDR high value means a better routing protocol. PDR can be formulated as follows:

\[ PDR = 100 \times \frac{\sum_{i=0}^{n} \text{Number of received Packets}}{\text{Total Number of Send Packets}} \]  

(1)

3. Normalized Routing Load (NRL): it is the total amount of data traffic being carried by the network. It is defined as the number of transmitted routing packets divided by the number of data packets delivered to the destination successfully. The network load happens when there is more traffic coming into the network, and it is difficult for it to handle this large amount of data. High network load reduces the packet delivery time to the destination [25]. The lower value of NRL means a better routing protocol. The following formula can be used to calculate NRL:

\[ NRL = 100 \times \frac{\text{Total Number of received packets}}{\text{Total Number of sent Packets}} \]  

(2)

| Table 1 Simulation parameters of network |
|-----------------------------------------|
| Simulator parameter | Values |
|----------------------|--------|
| Network simulator | NS-2 version 2.34 |
| Antenna model | Antenna/Omni Antenna |
| Radio-propagation model | Propagation/two ray ground |
| Channel type | Channel/wireless channel |
| Interface queue type | Queue/Drop Tail/PriQueue |
| MAC type | MAC/802.11 |
| Routing protocol | AODV and AOMDV |
| Number of vehicles | 50, 100, 150, 200, 250, 300, 350, 400, and 450 |
| No. of connections | 50% of number of vehicles |
| Vehicles speed | Min 10 m/s, Max 40 m/s |
| Simulation time | 100 S |
| Simulation area | (2000 × 1000) = 2 km² |
| Packet size | 512 Packets per Second |
| Initial node energy | 50, 60, 70, 80, 90, and 100 J |
4. Average End-to-End Delay (AETED): It is the time for one trip of data packet transmission from a source node to a destination node [26]. The AETED is the average time of all these network connection trips. Besides, it includes all possible delays caused by buffering during the route discovery latency, queuing at the interface queue, retransmission delays at the MAC, propagation delay, transfer times, and carrier sense delay for carrier sensors [27]. The lower delay indicates higher protocol performance [25]. VANET requires a small latency to deliver quick messages. The AETED can be computed as follows:

\[
AETED = \frac{\sum_{i=0}^{n} \text{Time at received packet} - \text{Time of sent Packet}}{\text{Total Number of received Packets}}
\]  

5. Average Throughput (ATP): It is the total number of packets that have been successfully delivered from source node to destination node in a particular time interval, the simulation Time Interval Length (TIL) [27]. It is considered a measure of how fast a node can actually send data through the network [26] to reach its destination. In addition to that, it is a measure used to determine the efficiency of the network. Moreover, it is the maximum data rate transfer between two terminal nodes in a network [27]. This item can be improved by increasing node density, and it is measured in bits or packets per sec. [24]. The ATP can be calculated as follows:

\[
\text{Average Throughput} = \frac{\text{Total of received packets} \times \text{packets size}}{\text{Total duration of the simulation (TIL)}}
\]  

5 Results Analysis

In this section, the simulation and performance investigation of AODV and AOMDV protocols are examined on the basis of the mentioned metrics, Sent Packets (SP), Packet Delivery Ratio (PDR), Normalized Routing Load (NRL), Average end-to-end delay (AETED), and Average Throughput (ATP). The node density changes between 50 and 450 nodes with a step of 50 nodes, and the initial node energy varies from 50 to 100 J with a step of 10 J. To compare the simulation results for AODV and AOMDV, the numerical formula of Root Relative Squared Error (RRSE) is applied. Mathematically, the RRSE of each step is evaluated by the following equation:

\[
\text{Table 2 Simulation parameters of scenario (1)}
\]

| Case study | Initial energy (X) | Parameter RRSE (Y) | Network size |
|------------|--------------------|-------------------|--------------|
| Case 1     | (50, 60…and 100 J)| SP                | This is performed at each network size, which is selected from 50 to 450 nodes with the step of 50 nodes |
| Case 2     |                    | PDR               |              |
| Case 3     |                    | NRL               |              |
| Case 4     |                    | AETED             |              |
| Case 5     |                    | ATP               |              |
\[ RRSE = \sqrt{\frac{\sum_{k=1}^{N} (x_f(k) - x_o(k))^2}{\sum_{k=1}^{N} (x_o(k) - \mu)^2}} \]  

where \( RRSE \) = Root Relative Squared Error, \( x_f(k) \) = The forecast value at sample \( k \), \( x_o(k) \) = The observed value at sample \( k \), \( \mu \) = The mean value. \( N \) = the number of observations.

The simulation results are analyzed for two scenarios.

### 5.1 The Effect of Initial Node Energy Change at a Certain Network Size

Table 2 summarizes five cases for the effect of initial node energy (50, 60, 70, 80, 90, and 100 J) as the X-axis, and the Y-axis is the performance parameter (SP, PDR, NRL, AETED, and ATP). This is performed at each network size, which is selected from 50 to 450 nodes with a step of 50 nodes. Where the number of vehicles connected is 50% of the network size.

The experiment is executed by measuring the performance metric at a certain network size, for example, 50 nodes, then changing the initial node energy, and finally putting the results in a table. The table for each case is computed based on Eq. (5) and put on the case table. In following figures P1 indicates the AODV protocol and P2 indicates the AOMDV protocol.

#### 5.1.1 Scenario (1) Case (1)

In case 1, Table 3 summarizes the RRSE values of sent packets (SP) of both AODV and AOMDV protocols, which are computed by Eq. (5). These values are plotted in Fig. 1a. For different network sizes and initial node energies between 70 and 100 J, the RRSE values of both protocols are similar and equal to zero. Except for RRSE values of AODV at network size of 200 nodes, while for AOMDV the RRSE values

| Initial Node Energy | The network Density Size | RRSE of SP at different initial node energy for AODV | RRSE of SP at different initial node energy for AOMDV |
|---------------------|--------------------------|-----------------------------------------------------|-----------------------------------------------------|
| 50-60               | 50 100 150 200 250 300 350 400 450 | 0.91 0.80 0.76 4.25 0.69 0.70 0.70 0.68 0.68 | 0.96 0.89 0.80 0.75 0.71 0.69 0.69 0.67 0.65 |
| 60-70               | 4.06 2.51 2.30 0.68 2.05 2.07 2.08 2.03 2.02 | 7.19 3.54 2.52 2.23 2.11 2.07 2.05 2.00 1.97 |
| 70-80               | 0.00 0.00 0.00 1.23 0.00 0.00 0.00 0.00 0.00 | 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 |
| 80-90               | 0.00 0.00 0.00 0.26 0.00 0.00 0.00 0.00 0.00 | 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 |
| 90-100              | 0.00 0.00 0.00 0.01 0.00 0.00 0.00 0.00 0.00 | 0.07 0.03 0.05 0.00 0.00 0.00 0.00 0.00 0.00 |
are equal to zero and for network sizes of 50, 100, and 150 nodes, the RRSE values of AODV are better than AOMDV. At network sizes of 50, 100, 150, and 250 nodes and the initial node energy between 50 and 70 J the RRSE values of AODV are less than those of AOMDV. Vice versa, for the network sizes of 300, 350, 400, and 450 nodes and the initial node energy between 50 and 70 J, the RRSE values of AOMDV are less than those of AODV.

5.1.2 Scenario (1) Case (2)

In case (2), Table 4, the RRSE values of Packet Delivery Ratio (PDR) for AODV and AOMDV routing protocols are mentioned and plotted in Fig. 1b. For different network sizes and initial node energies between 70 and 100 J the RRSE values of PDR for both protocols are similar and equal to zero, except for network sizes between 50 and 150 nodes and initial node energies between 90 and 100 J, the RRSE values of PDR for AODV are only equal to zero. In addition, at network size of 200 nodes and initial node energies between 70 and 100 J, the RRSE values of AOMDV are better than AODV and are equal to zero. It is also about 0.90 between 50 and 60 J, and between 60 and 70 J, the RRSE values of AODV are better than AOMDV and approximately equal to 0.74. The RRSE values of AOMDV are better than AODV at network size of 50 nodes and initial node energies are between 50 and 60 J. When the initial node energy is between 60 and 70 J and between 90 and 100 J, the RRSE values of AODV are better otherwise both protocols have equilibrium and zero RRSE values. At a network size of 100, 300 and 450 nodes and an initial node energy of between 50 and 60 J, the RRSE values of AODV are better than those of AOMDV. This is also valid for network sizes of 50, 200, 300, and 450 nodes at an initial node energy of between 60 and 70 J. The RRSE values of AOMDV are better than AODV for the network sizes of 50, and 200 nodes for initial node energies between 50 and 60 J. Also, at network size of 100 nodes and an initial node energy between 60 and 70 nodes. For the network, sizes of 150, 250, 350 and 400 nodes at initial node energy between 50 and 70 J the RRSE values of PDR for AOMDV are better than AODV.

5.1.3 Scenario (1) Case (3)

In case (3), it is concluded in Table 5, and it is plotted in Fig. 1c, which presents the RRSE values of Normalized Routing Load (NRL) for AODV and AOMDV at different network densities. The results show that when the initial energy is between 70 and 100 J, the RRSE values of NRL for different network sizes show that both protocols are at equilibrium and their values are equal to zero. Except for initial node energy between 90 and 100 J, the RRSE values of AODV are better than AOMDV and equal to zero, while AOMDV are not equal to zero. In addition, at a network size of 200 nodes, the RRSE values of AOMDV are equal to zero and the RRSE values for AODV are not equal to zero. For initial node energy between 50 and 70 J and network size between 50 and 350 nodes, the RRSE values of AODV are better than AOMDV, and for 400 and 450 nodes, the RRSE values of AOMDV are better than AODV. When the
initial node energy is between 60 and 70 J and the network density of 50, 250, 300, 350, 400, and 450 nodes, the RRSE values of AOMDV are better than the AODV. When the network size is between 100 and 150 nodes, the RRSE values of AODV are better than AOMDV.

5.1.4 Scenario (1) Case (4)

In case (4), the results of RRSE values of AODV and AOMDV at different network densities are summarized in Table 6 and are plotted in Fig. 1d for AETED. The results illustrate that when the initial node energies between 70 and 90 J, the RRSE values of both protocols are equal to zero. In addition, for network size densities greater than 200 nodes, the RRSE of both protocols between 90 and 100 is zero. For initial node energy between 50 and 60 J, for all network sizes that are less than 400 nodes, the RRSE values of AOMDV are better than those of AODV. On the other side when network density is more than 400 nodes, the RRSE values of AODV are better than that of AOMDV and are equal to zero. Between 60 and 70 J, the AODV has RRSE values that are lower, equal to zero and better than those of the AOMDV for all network densities except at 200 nodes, which is not equal to zero.

5.1.5 Scenario (1) Case (5)

In case (5), the information is illustrated in Table 7, and it appears in Fig. 1e. It presents the average throughput (ATP) of RRSE values for AODV and AOMDV at different network densities. The results reveal that when the initial node energies are between 70 and 90 J, the RRSE values of both protocols are similar and equal to zero. Also, when the number of nodes is greater than 200, the RRSE values of both protocols between 90 and 100 J are zero. When the number of nodes is less than 200 nodes, the RRSE values of AODV are equal to zero only. For initial node energy between 50 and 60 J and network density is less than 200 nodes the RRSE values of AODV are better than AOMDV. Otherwise, they are for AOMDV are better. For the initial node, energies between 60 and 70 J the RRSE values for the AODV are better than that of AOMDV, which is equal to zero for all network densities.

5.2 The Effect of Network Density Change at a Certain Initial Node Energy

The simulation cases of scenario (2) are calculated from Eq. (5) and are summarized in Table 8. It lists five cases studies with the X-axis is the network size (50, 100, 150, 200, 250, 300, 350, 400, and 450) nodes and the Y-axis is the performance parameter (i.e. SP, DPR, NRL, AETED, and ATP) at a certain initial node.
energy (50, 60, 70, 80, 90 and 100 J). The following figures has (P1) which indicates the AODV protocol and (P2) which indicated the AOMDV protocol.

5.2.1 Scenario (2) Case (1)

For scenario (2) case (1) Table 9 shows the RRSE values for sent packets (SP). The results are plotted in Fig. 2 (a) where the X-axis is the network size density (50,100...450) and the Y-axis is the sent packets at different initial node energy. For
Table 4  Scenario (1) case (2), the effect of changing initial node energy at different network density for the Packet Delivery Ratio (PDR)

| Initial Node Energy | The network Density Size |
|---------------------|--------------------------|
|                     | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 |
| 50-60               | 1.08 | 0.72 | 0.86 | 1.21 | 0.93 | 0.77 | 0.89 | 0.86 | 0.79 |
| 60-70               | 1.78 | 2.14 | 3.08 | 0.74 | 4.87 | 2.35 | 3.46 | 3.04 | 2.42 |
| 70-80               | 0.00 | 0.00 | 0.00 | 1.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 80-90               | 0.00 | 0.00 | 0.00 | 0.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-100              | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 5  Scenario (1) case (3), the effect of changing initial node energy at different network density for Normalized Routing Load (NRL)

| Initial Node Energy | The network Density Size |
|---------------------|--------------------------|
|                     | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 |
| 50-60               | 0.96 | 1.93 | 0.31 | 0.90 | 0.79 | 1.00 | 0.76 | 0.83 | 0.87 |
| 60-70               | 2.83 | 0.50 | 0.15 | 3.66 | 2.42 | 5.20 | 2.31 | 2.74 | 3.21 |
| 70-80               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 80-90               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-100              | 11.56 | 3.84 | 5.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
Table 6  Case (4), the effect of changing initial node energy at different network density for average end-to-end delay (AETED)

| Initial Node Energy | The network Density Size | RRSE of AETED at different initial node energy for AODV |
|---------------------|--------------------------|--------------------------------------------------------|
|                     | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 |
| 50-60               | 1.20 | 1.20 | 1.20 | 9.51 | 1.20 | 1.20 | 1.20 | 0.00 | 0.00 |
| 60-70               | 0.00 | 0.00 | 0.00 | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 70-80               | 0.00 | 0.00 | 0.00 | 1.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 80-90               | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-100              | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RRSE of AETED at different initial node energy for AOMDV |
| 50-60               | 0.95 | 1.04 | 0.82 | 0.75 | 0.72 | 0.69 | 0.70 | 0.67 | 0.65 |
| 60-70               | 4.27 | 7.33 | 2.87 | 2.24 | 2.15 | 2.05 | 2.07 | 2.00 | 1.97 |
| 70-80               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 80-90               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-100              | 1.88 | 1.01 | 0.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 7  Scenario (1) case (5), the effect of changing initial node energy at different network density for Average Throughput (ATP)

| Initial Node Energy | The network Density Size | RRSE of ATP at different initial node energy for AODV |
|---------------------|--------------------------|------------------------------------------------------|
|                     | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 |
| 50-60               | 1.20 | 1.20 | 1.20 | 9.51 | 1.20 | 1.20 | 1.20 | 0.04 | 0.06 |
| 60-70               | 0.00 | 0.00 | 0.00 | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 70-80               | 0.00 | 0.00 | 0.00 | 1.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 80-90               | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-100              | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RRSE of ATP at different initial node energy for AOMDV |
| 50-60               | 0.95 | 1.04 | 0.82 | 0.75 | 0.72 | 0.69 | 0.70 | 0.67 | 0.65 |
| 60-70               | 4.27 | 7.33 | 2.87 | 2.24 | 2.15 | 2.05 | 2.07 | 2.00 | 1.97 |
| 70-80               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 80-90               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-100              | 1.88 | 1.01 | 0.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
network size between 50 and 250 nodes and initial node energy of 50, 60 and 70 J, the RRSE values of AODV are better than AOMDV and both protocols have similar RRSE values between 100 and 150 at 60 J and between 50 and 150 at 70 J. At initial node energy 50 J and network sizes between 250 and 400 nodes, the RRSE values of AODV are better than AOMDV, also at network sizes between 350 and 400 nodes at 60 and 70 J and for network size at 400 to 450 nodes at 70 J. For network sizes,
between 250 and 450 nodes, and with the initial node energy between 80, and 100 J the AODV protocol has better RRSE values.

5.2.2 Scenario (2) Case (2)

For scenario (2), case (2), Table 10 illustrates the RRSE values of the Packet Delivery Ratio (PDR) for AODV and AOMDV at different network densities at certain initial node energies. In general, the RRSE of Packet Delivery Ratio (PDR) for AODV is better than that of AOMDV except for network sizes between 350 and 400 nodes at different initial node energies, for network size between 100 and 150 nodes at 70 J. For networks with size between 150 and 200 nodes, at initial node energies between 60 and 90 J. Furthermore, for network size between 350 and 400 nodes, at all initial node energy.

5.2.3 Scenario (2) Case (3)

For scenario (2), case (3), Table 11, Fig. 2c concludes the RRSE values of Normalized Routing Load (NRL) at different network sizes and the selected initial node energy. In general, the RRSE values of AODV are better than AOMDV excluding the network size between 200 and 250 nodes, also between 350 and 400 nodes, and between 150 and 200 nodes, at 50, and between 70 and 90 J.

5.2.4 Scenario (2) Case (4)

For scenario (2), case (4), Table 12 and Fig. 2d present the RRSE values of average End-to-End Delay (AETED) at variable network size each time at a certain initial node energy. The RRSE values of AOMDV are better than AODV excluding network size densities between 50 and 100 nodes at 50 and 100 J. Also, at network sizes between 100 and 150 nodes at 50 J, at network size densities between 350 and 400 nodes at 60 J. In addition, for network size densities between 200 and 250 nodes and 300 and 350 nodes at all initial node energies.
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(a) RRSE of SP for both P1 and P2
(b) RRSE of PDR for both P1 and P2
(c) RRSE of NRL for both P1 and P2
5.2.5 Scenario (2) Case (5)

For scenario (2), case (5), is illustrated in Table 13 and Fig. 2e. It presents the RRSE values of average throughput (ATP) at variable network densities at a certain initial node energy. The average throughput of AODV is better than AOMDV for all network densities, the RRSE values are equal to zero for AODV at network densities between 50 and 150 nodes and between 250 and 450 nodes. In addition to between 200 and 250 nodes. On the other side, the RRSE values of AOMDV are better between 150 and 200 nodes at initial node energy of 50, 70, 80, 90, and 100 J.
Table 10 Scenario (2) case (2), the effect of change network size on the PDR at certain initial node energy

| Scenario | RRSE of PDR at different initial node energy for AODV | RRSE of PDR at different initial node energy for AOMDV |
|----------|---------------------------------------------------|---------------------------------------------------|
|          | RRSE                                             | RRSE                                             |
| Nodes    | 50  | 60  | 70  | 80  | 90  | 100 | 50-100 | 9.46 | 1.62 | 1.14 | 1.14 | 1.14 | 0.74 |
|          | 50-100 | 0.39 | 0.43 | 0.57 | 0.52 | 0.52 | 0.52 |
|          | 100-150 | 0.55 | 0.74 | 0.88 | 0.73 | 0.72 | 0.72 |
|          | 150-200 | 2.52 | 8.10 | 28.36 | 5.57 | 4.60 | 4.32 |
|          | 200-250 | 1.47 | 1.40 | 1.35 | 1.51 | 1.55 | 1.56 |
|          | 250-300 | 0.10 | 0.14 | 0.09 | 0.10 | 0.11 | 0.11 |
|          | 300-350 | 0.38 | 0.31 | 0.21 | 0.25 | 0.26 | 0.26 |
|          | 350-400 | 0.28 | 0.22 | 0.19 | 0.22 | 0.22 | 0.22 |
|          | 400-450 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 |
|          | 50-100 | 0.66 | 0.90 | 0.80 | 0.80 | 0.80 | 1.14 |
|          | 100-150 | 4.84 | 2.24 | 0.58 | 0.58 | 0.58 | 9.46 |
|          | 150-200 | 0.71 | 1.22 | 1.48 | 1.48 | 1.48 | 1.32 |
|          | 200-250 | 2.96 | 5.80 | 2.05 | 2.05 | 2.05 | 2.75 |
|          | 250-300 | 0.62 | 0.40 | 0.28 | 0.28 | 0.28 | 0.30 |
|          | 300-350 | 0.12 | 0.13 | 0.08 | 0.08 | 0.08 | 0.09 |
|          | 350-400 | 3.10 | 1.00 | 0.75 | 0.75 | 0.75 | 0.84 |
|          | 400-450 | 2.58 | 2.46 | 2.46 | 1.88 | 1.13 | 1.16 |

Table 11 Scenario (2) case (3), the RRSE of NRL of AODV and AOMDV at different network size and certain initial node energy

| Scenario | RRSE of NRL at different initial node energy for AODV | RRSE of NRL at different initial node energy for AOMDV |
|----------|---------------------------------------------------|---------------------------------------------------|
|          | NNRL                                             | NNRL                                             |
| Nodes    | 50  | 60  | 70  | 80  | 90  | 100 | 50-100 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 |
|          | 100-150 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 |
|          | 150-200 | 2.58 | 2.46 | 2.46 | 1.88 | 1.13 | 1.16 |
|          | 200-250 | 1.33 | 1.29 | 1.30 | 1.44 | 3.54 | 3.01 |
|          | 250-300 | 0.20 | 0.44 | 0.34 | 0.42 | 0.56 | 0.55 |
|          | 300-350 | 0.76 | 0.85 | 0.81 | 0.95 | 1.15 | 1.14 |
|          | 350-400 | 12.90 | 20.10 | 16.59 | 65.78 | 29.68 | 31.60 |
|          | 400-450 | 0.38 | 0.39 | 0.33 | 0.31 | 0.30 | 0.30 |
|          | 50-100 | 0.13 | 0.12 | 0.23 | 0.23 | 0.23 | 0.20 |
|          | 100-150 | 0.73 | 1.11 | 1.28 | 1.28 | 1.28 | 0.82 |
|          | 150-200 | 1.92 | 3.88 | 1.05 | 1.05 | 1.05 | 4.55 |
|          | 200-250 | 0.98 | 0.26 | 0.19 | 0.19 | 0.19 | 0.17 |
|          | 250-300 | 61.30 | 0.51 | 0.81 | 0.81 | 0.81 | 0.72 |
|          | 300-350 | 1.24 | 2.42 | 6.49 | 6.49 | 6.49 | 3.91 |
|          | 350-400 | 0.50 | 0.53 | 0.54 | 0.54 | 0.54 | 0.50 |
|          | 400-450 | 0.97 | 1.40 | 1.07 | 1.07 | 1.07 | 0.90 |
The autonomous vehicles are a key component of the intelligent transportation system (ITS), and their increasing network size drives researchers to develop an efficient and fast routing protocol, in addition to improving road safety. In this paper, two different reactive routing protocols, AODV and AOMDV, have been investigated for communications among autonomous vehicles. They have been simulated using NS-2.34. The simulation results have been obtained for different performance parameters such as sent packets, packet delivery ratio, normalized routing load, average end-to-end delay, and average throughput. These parameters have been evaluated using the RRSE concept.

Two different experiments have been presented: the first examines the effect of initial node energy changes at a certain network size. The RRSE values are similar and are equal to zero for AODV and AOMDV when initial node energy is greater than 70 J and for network sizes. The RRSE values of sent packets, packet delivery ratio, normalized theorem.

### Table 12

| Scenario (2) case (4), the RRSE of AETED of AODV and AOMDV at different network size and certain initial node energy |
|---------------------------------------------------------------|
| **RRSE of AETED at different initial node energy for AODV**    |
| Nodes | 50 | 60 | 70 | 80 | 90 | 100 |
|-------|----|----|----|----|----|-----|
| 50-100| 0.37 | 0.63 | 0.59 | 0.59 | 0.59 | 0.59 |
| 100-150| 0.40 | 1.44 | 0.90 | 0.90 | 0.90 | 0.90 |
| 150-200| 1.08 | 0.92 | 1.47 | 1.47 | 1.47 | 1.47 |
| 200-250| 1.13 | 1.10 | 1.06 | 1.06 | 1.06 | 1.06 |
| 250-300| 1.73 | 3.33 | 5.92 | 5.92 | 5.92 | 5.92 |
| 300-350| 0.03 | 0.84 | 0.77 | 0.77 | 0.77 | 0.77 |
| 350-400| 2.23 | 0.15 | 4.84 | 4.84 | 4.84 | 4.84 |
| 400-450| 0.69 | 0.23 | 0.72 | 0.72 | 0.72 | 0.72 |

| **RRSE of AETED at different initial node energy for AOMDV** |
|---------------------------------------------------------------|
| Nodes | 50 | 60 | 70 | 80 | 90 | 100 |
|-------|----|----|----|----|----|-----|
| 50-100| 0.95 | 0.00 | 0.00 | 0.00 | 0.00 | 4.50 |
| 100-150| 0.73 | 0.60 | 0.58 | 0.58 | 0.58 | 0.16 |
| 150-200| 0.84 | 0.75 | 0.73 | 0.73 | 0.73 | 0.84 |
| 200-250| 1.80 | 1.50 | 1.38 | 1.38 | 1.38 | 1.80 |
| 250-300| 1.13 | 1.50 | 1.80 | 1.80 | 1.80 | 1.13 |
| 300-350| 18.00 | 6.00 | 6.75 | 6.75 | 6.75 | 27.00 |
| 350-400| 2.12 | 2.40 | 1.17 | 1.17 | 1.17 | 1.04 |
| 400-450| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

The list of symbols and abbreviations, used in this paper are listed in Table 14.

### 6 Conclusion

The autonomous vehicles are a key component of the intelligent transportation system (ITS), and their increasing network size drives researchers to develop an efficient and fast routing protocol, in addition to improving road safety. In this paper, two different reactive routing protocols, AODV and AOMDV, have been investigated for communications among autonomous vehicles. They have been simulated using NS-2.34. The simulation results have been obtained for different performance parameters such as sent packets, packet delivery ratio, normalized routing load, average end-to-end delay, and average throughput. These parameters have been evaluated using the RRSE concept. Two different experiments have been presented: the first examines the effect of initial node energy changes at a certain network size. The RRSE values are similar and are equal to zero for AODV and AOMDV when initial node energy is greater than 70 J and for network sizes. The RRSE values of sent packets, packet delivery ratio, normalized routing load, average end-to-end delay, and average throughput.
Table 13 Scenario (2) case (5), the RRSE of the ATP of AODV and AOMDV at different network size and certain initial node energy

| Nodes        | 50  | 60  | 70  | 80  | 90  | 100 |
|--------------|-----|-----|-----|-----|-----|-----|
| 50-100       | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 100-150      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 150-200      | 9.00| 9.00| 9.00| 9.00| 9.02| 9.02|
| 200-250      | 1.13| 1.13| 1.13| 1.13| 1.13| 1.13|
| 250-300      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 300-350      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 350-400      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 400-450      | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|

| Nodes        | 50  | 60  | 70  | 80  | 90  | 100 |
|--------------|-----|-----|-----|-----|-----|-----|
| 50-100       | 0.20| 0.29| 0.24| 0.24| 0.24| 0.10|
| 100-150      | 0.39| 0.28| 0.31| 0.31| 0.31| 0.32|
| 150-200      | 0.96| 0.84| 0.77| 0.77| 0.77| 0.81|
| 200-250      | 5.10| 1.67| 1.30| 1.30| 1.30| 1.40|
| 250-300      | 0.03| 0.82| 3.00| 3.00| 3.00| 2.39|
| 300-350      | 3.28| 3.08| 1.96| 1.96| 1.96| 1.85|
| 350-400      | 1.17| 0.97| 0.93| 0.93| 0.93| 0.91|
| 400-450      | 0.16| 0.22| 0.27| 0.27| 0.27| 0.27|

Routing load for AOMDV are better than those of AODV for initial node energies, which lies between 50 and 70 J, and network sizes are greater than 200 nodes. The RRSE values of AETED of AODV are better than AOMDV for initial node energy between 50 and 60 J and network densities are less than 400 nodes. The RRSE values of ATP are better of AOMDV for initial node energy, which is located between 50, 60 J, and network sizes greater than 150 nodes. The second experiment studies the effect of network density changes at a considerable node initial energy. Generally, the RRSE values for AODV are better than those of AOMDV for sent packets, packet delivery ratio normalized routing load, and average throughput. The RRSE values of AETED for AOMDV are better than those of AODV. In the future work new metrics will be evaluated for these protocols using a variation of transmission range and a speed change with other parameters such as packet loss and residual energy. In addition, the effect of the combination of AODV and AOMDV on the same environment will be validated. Furthermore, the security of VANET protocols will be enhanced.
Table 14  List of symbols and abbreviation

| Symbols  | Abbreviations                          |
|----------|----------------------------------------|
| AETED    | Average end to end delay               |
| AODV     | Ad-hoc on-demand distance vector (P1) protocol |
| AOMDV    | Ad-hoc on-demand multipath distance vector (P2) protocol |
| ASTAR    | Anchor based street and traffic aware routing |
| ATP      | Average throughput                     |
| CBF      | Contention-based forwarding             |
| DSDV     | Destination sequence destination vector|
| DYRO     | Dynamic MANET on-demand                |
| GPCR     | Greedy perimeter coordinator routing    |
| GPSR     | Greedy Perimeter Stateless Routing      |
| MANET    | Mobile Ad-hoc network                  |
| OLSR     | Optimized link state routing            |
| PDR      | Packet delivery ratio                  |
| RERR message | Rout error message                   |
| RREQ message | Route request message             |
| RRSE     | Root relative squared error            |
| SP       | Sent packet                            |
| TIL      | Time interval length                   |
| VANET    | vehicular ad-hoc network               |
| ZRP      | Zone routing protocol                  |

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**Declarations**

**Conflict of interest**  We have no conflicts of interest to disclose.

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