Comparative analysis of reactive routing protocols for vehicular adhoc network communications

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ABSTRACT

In the recent past, vehicular adhoc networks (VANETs) have gained a lot of importance. The routing protocols play a vital role to deliver payloads from one vehicle to another one while they are moving at relative speeds. It is a challenging task to select a routing protocol for VANETs because of the uneven distribution and high mobility of vehicles. In this paper, we have analysed the two standard reactive protocols, adhoc on-demand distance vector (AODV) and ant colony optimization (ACO). The performance comparison of AODV and ACO routing protocols has been presented in this paper. The results show AODV performed better in terms of energy consumption and routing overhead. While considering the throughput, energy loss ratio, and delay ACO has performed. ACO resulted as upperhand.

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1. INTRODUCTION

According to the commitment made by 183 nations under sustainable development goals (SDGs), a move is required to end poverty and make a revolution toward the future for shared progress [1]. These goals are aspiring, computable, and action-oriented. Goal number 3 ensures reduce in the number of global death which occurs due to road accidents [2]. Reasons for road accidents are inattentiveness of the driver while driving the car, overspeeding, drunk driving, red light jumping, overtaking in a wrong manner, distractions to the driver, and so on [3], [4]. The burst in the number of accidents demands the development of safe and comfortable procedures and technical support while driving. The application should be such that it could request, broadcast, and share information among vehicles and road side units (RSUs) resulting in intelligent transport system (ITS) [5], [6]. Improved road safety measures could be provided to the driver by offering reliable and timely data. To achieve this, the challenges in vehicular adhoc networks (VANET) which is the key to implementing ITS are to be overcome. The major challenge posed by the dynamic nature of VANET emphasizes the performance of routing protocol [7], [8]. This paper aims to explore a study of the reactive routing protocol, adhoc on-demand distance vector (AODV), and an adaptive routing protocol called ant colony optimization (ACO), to contribute to real-time applications [9], [10].

The rest of the paper is organized into ten sections. Section 1 is introduction, section 2 provides a basic overview of the VANET and its routing protocols, section 3 presents the details about the related work, sections 4 explain the AODV routing protocol, section 5 describes the ACO routing protocol and section 6 provides a MATLAB implementation of the AODV and ACO of the VANET scenario, section 7 explains the adopted methodology, section 8 provides simulation results, section 9 presents discussion, and section 10 concludes the work.

2. VEHICULAR ADHOC NETWORK

VANET includes wireless nodes which behave as vehicles. The communication between nodes can be through vehicle to vehicle (V2V) or vehicle to infrastructure (V2I). A vehicle can move around the network or remain in one location for a while and the communication between the vehicle and the infrastructure can be wired or wireless. The communication is done with the help of the on-board units (OBUs) equipped on them. When implementing VANETs, real-time road conditions are considered [11].

This work is focused on implementing the VANETs scenario on the simulation tool MATLAB for AODV and ACO routing protocol. Different parameters considered are throughput, packet loss ratio, routing overhead, delay, and energy consumption. Comparison based on these parameters has been made between these routing protocols. A VANET comprises many randomly moving vehicles and a boundary-less road network. In urban areas, the road traffic scenario is dense compared to rural areas. Therefore, the selection of routing protocol for the VANET environment should be based on the requirements like efficiency, scalability, and compatibility with standards [9]. An overview of different types of routing protocols is given below.

a. The topology-based routing protocol routing table plays a major role to store all the information about the source, intermediate, and destination nodes. A topological-based routing protocol is based on the routing table. It can be proactive, reactive, or hybrid. To update the information about the network, the proactive routing protocol is used. To determine the structure of a network reactive routing protocol is used. The hybrid routing protocol is a combination of both proactive and reactive protocols. AODV and dynamic source routing protocol (DSR) are topology-based routing protocols [12], [13].
b. Position-based routing protocol uses the position of the vehicle to analyse the communication between them. In this the position of the neighboring node is located by using a beaconing message and the position of the destination node is determined by using the global positioning system (GPS) service. Position-based routing protocol does not include route maintenance and route establishment [11].
c. Cluster-based routing protocol forms clusters between the nodes/vehicles. A cluster head is selected within the cluster. The intra-vehicle and inter-vehicle communication occur only through cluster heads. clustering for open IVC networks (COIN) is a cluster-based routing protocol [14], [15].

While making optimized solutions knowledge about the network, environment, and mobility is a must. Context-aware routing protocol collects all the information regarding the node as well as its network and optimizes the solution. All the collected data is used to increase the performance of the network. Two major protocols under this category are ACO and AntNet [16], [17].

3. RELATED WORK

Malik and Sahu [13] studied and evaluated two different routing protocols, AODV and DSR for VANETs. The evaluation was done using NetSim and SUMO tools. The study was done to select the best routing protocol for reliable data packet transmission. The results showed that a combination of a routing protocol with a fixed network size can enhance throughput for VANETs. The author proposed enhanced DSR to get better results for throughput, delay, and packet delivery ratio.

Aadil *et al.* [15] explained the concept of cluster head along with inter-cluster and intracluster to improve the efficiency of communication. An algorithm clustering algorithm based on ACO for VANETs (CACONET) was proposed which included the concept of ACO along with clustering. Different experiments were performed by varying the number of nodes, transmission range, and grid size of the network. The parameters used for comparing the results were the speed of the vehicle, the direction of the vehicle, and the transmission range of the vehicle. The proposed algorithm resulted in the selection of a fewer number of clusters thereby reducing the routing overhead. The results showed that CACONET performs better in heavy-traffic areas.

Del-Valle-Soto *et al.* [18] proposed a wireless sensor network energy model. A combination of transmission and receiving energy that forms an energy consumption model is explained at each node. The author has explained the energy consumption model for routing protocols like AODV, dynamic source routing (DSR), power-efficient gathering in sensor information systems (PEGASIS), zigbee tree routing (ZTR), and low energy adaptive clustering hierarchy (LEACH), which come under the category of proactive, reactive, and energy-aware. The author proposed a multi-parent hierarchical (MPH) routing protocol and compared the results. Experimental results showed that MPH performed better than AODV, DSR, and ZTR. Energy consumption of MPH was a bit high 2-3% than PEGASIS and LEACH.

Zhang *et al.* [19] surveyed ACO under the category of Swarm intelligence-based algorithm which is based on optimized NP-hard problem. The principles of ACO routing protocol for wireless mobile ad hoc networks (MANETs) were studied. Basic routing protocols like AntNet, ARA, PERA, AntHocNet, PACONET were studied for MANETs. These protocols are best suitable for dynamically changing networks. The behaviour of these protocols indicates that ACO gives a better solution for the problems in routing for MANETs.

Waraich and Batra [20] analysed AODV, DSR, geographic perimeter stateless routing (GPSR), LAR, and OLSR over different QoS parameters such as packet delivery ratio, routing load, throughput, and jitter over VANETs. The simulator used for evaluation was simulation of urban mobility (SUMO). According to the results, AODV and zone routing protocol (ZRP) have high throughput and packet delivery ratios. AODV resulted in less routing overhead and delay as compared to DSR.

Rezaeifar *et al.* [21] studied existing routing protocols from the perspective of geocast. A new approach was proposed to decrease the overhead and improve the packet delivery ratio with less delay. Parameters used for comparison were packet loss, overhead, packet delivery ratio, and delay. A mesh-type scenario was generated with 4 horizontal and 3 vertical divisions. The result showed that the proposed method reduced delay and routing overhead and increases the packet delivery ratio.

Habib and K. [22] studied proactive, reactive, and hybrid routing protocols. To bring improvement in the performance of the destination sequenced distance vector (DSDV) proactive routing protocol author proposed a technique using software defined networking (SDN). According to the author, the controller, and switch within the SDN helps in finding the best route between the source and destination. By using SDN packet delay was improved for DSDV.

Ahamed and Vakilzadian [23] enhanced the AODV routing protocol by reducing the route request (RREQ) and route reply (RREP) messages. This was done by enhancing direction parameters and following two-step filtering. This resulted in reduced packet overhead and a stable route was found. The results also showed that there was a reduction in packet loss and end-to-end delay in AODV. The newly developed protocol showed an increase in throughput, around 1% downfall in packet loss, and around 11% downfall in end-to-end delay.

Silva *et al.* [24] studied GPSR and analysed its shortcomings. Based on the shortcomings of GPSR author proposed a new strategy named path aware GPSR (PA-GPSR). The most important feature added to the new strategy was an extension in the neighboring table which is used to select the nodes with the best path and ignore the nodes which previously lead to recovery mode. The simulators used were SUMO and NS-3. The results of the proposed routing protocol were more suitable in terms of packet delivery rate and delay. The proposed algorithm overcomes link breakage which was caused due to road accidents or end roads.

Mor [25] discussed improved AODV in VANETs and proposed AODV_broadcasting data packet (AODV_BD) routing protocol to reduce packet delay and to make the route stable. In AODV_BD the data packet is broadcasted during a local repair. The author also provided a digital signature to identify RREQ and RREP messages. This was done by presenting a cross-layer technique to find channel security for the AODV routing protocol. This was done to enhance safety within the vehicles.

Nidhi [26] simulated AODV for VANETs using MOVE and SUMO on a real map of JNU New Delhi. While transferring data clustering was considered on smaller routes. Different parameters like route dropout, packet loss, and average delivery ratio were considered for analysing the performance of the AODV routing protocol.

4. ADHOC ON-DEMAND DISTANCE VECTOR

In general, AODV is being used in MANETs and internet of things (IoT) applications; this has become a universal standard to test the performance of any new routing protocols. AODV routing protocol is a reactive routing protocol that is routes are created only when there is a demand for route creation. It does not maintain all routes at all times and this results in less overhead. AODV utilizes a routing table to store routing information. AODV operates in the following two phases [18]:

a. Route discovery; route request (RREQ) and route reply (RREP)
b. Route maintenance: route error (RERR)

Every node maintains two counters

a. Sequence number
b. Broadcast_id: as the source issues a new RREQ broadcast_id is incremented.

Source broadcast RREQ data packet for searching a route:

< source_sequence_no, source_address, boradcast_id, dest_address, Hop_count>

Destination unicast RREP:

<source_address, destination_address, sequence_number, hop_count, lifetime>

Intermediate node: Discard duplicate packet

Route maintenance: Constant monitoring of the routing table to notice invalid routes and repairing is done by the route maintenance phase.

Figure 1 illustrates the flow of messages for searching the path between the source and destination. Black lines represent connectivity between the nodes. The red arrow represents RREQ which is initialized from the source. Green arrow lines represent RREP which is initialized from the destination.

a. When a node does not have a valid route to the destination RREQ is forwarded.
b. When intermediate nodes receive RREQ packet two cases are possible

- If there is not a valid route to the destination then nodes forward the packet.
- If there is a valid route to the destination then the node prepares a route reply message.
- When a route request is received multiple times, duplicate copies are discarded.

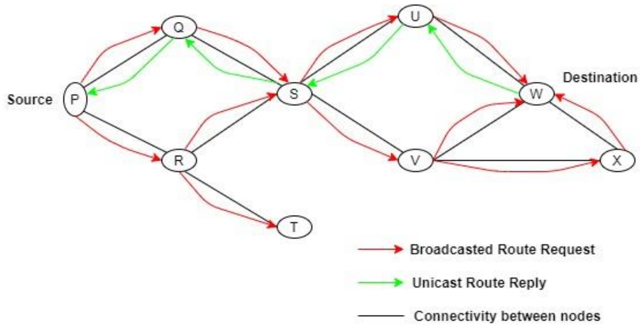

Figure 1. AODV path discovery

When time expires before receiving RREP, then the entry is deleted [18]. Multiple routes are found while reaching the destination. Hop count is the number of nodes required to reach the destination from the source. So the route which has a minimum hop count is selected as the final route [23].

Route 1: P→Q→S→U→W hop count=4
Route 2: P→R→S→U→W hop count=4
Route 3: P→R→S→V→X→W hop count=5

5. ANT COLONY OPTIMIZATION

ACO is a swarm based optimization algorithm. It is a metaheuristic approach used to solve real-world problems [15]. In the ACO algorithm ants are the agents which move from source to destination. It shows how the ants search the food, though they are visionless and carry the food back to their anthill. Ant deposits the chemical substance called pheromone on the path travelled by them. Pheromones evaporate over a certain duration of time. Pheromones help ants to decide the path to be followed; this process is known as stigmergic communication [27].

Figure 2 illustrates a basic scenario of finding the path by ants. At the initial stage, all ants move in an unplanned manner from source to destination. At diversion, D1 few ants move toward path P1 and a few ants move toward path P2. Similarly, at diversion D2 few ants move towards path P3 and a few remain on the same path P2. The distance between the diversions D1 to D2 is less through path P2 as compared to path P1. The distance for path P2 is less as compared to path P3. So as the ant keeps on moving the pheromone level through path P2 will be high and after some time, the entire ant will travel through path P2.

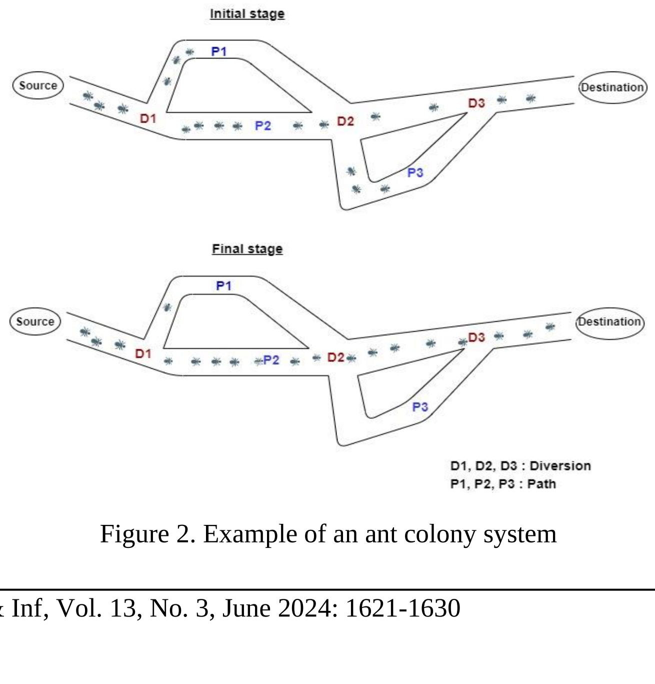

Figure 2. Example of an ant colony system

The probability for an ant K to move from source city i to destination j at time t is denoted as (1) [19]:

$$P_{ij}^{k}(t) = \frac{[T_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum_{h \in \text{allowed k(t)}} [T_{ij}(t)]^{\alpha} \cdot [\eta_{ih}]^{\beta}} \quad (1)$$

Where P_ij^k(t) is the probability of ant k moving from city i to j at time t; α, β is parameters used to control the effect of pheromones and distance; Tij(t) is pheromone present on edge ij at time t; and ηij is the visibility which is inversely proportional to the distance between source i and destination j.

After constructing the tour in n time steps, each ant deposits:

Amount of pheromones on the edges:

$$\frac{Q}{Lk} \quad (2)$$

Total pheromone deposited on edge ij is:

$$\Delta\, \tau_{ij}(\mathrm{t}, \mathrm{t}+\mathrm{n}) \quad (3)$$

Updated pheromones on edge are:

$$T_{ij}(t+n) = (1-\rho) * T_{ij}(\mathrm{t}) + \Delta\, T_{ij}(\mathrm{t}, \mathrm{t}+\mathrm{n}) \Delta\, \tau_{ij}(\mathrm{t}, \mathrm{t}+\mathrm{n}) \quad (4)$$

Where Lk is length of the complete tour, Q is appropriate constant, and ρ is evaporation rate of pheromone

6. IMPLEMENTATION

After studying the working of both AODV and ACO routing protocols. These protocols were implemented on the MATLAB simulator. This section discusses the selection of factors that were considered for the implementation of both protocols.

The AODV and ACO routing protocols were implemented virtually using VANETs for the identical circumstances of moderate traffic in a 1000*1000 m^2 region. A data packet of 512 bytes was transmitted from source to destination. For implementation 10 parallel horizontal lanes were created and the traffic flow considered was bi-directional. To obtain more appropriate results the simulation was conducted for 50 times. For transmitting and receiving the data packet, an energy of 50 nJ/bit was considered. After transmitting and receiving the data packet, the parameters such as throughput, network lifetime, packet loss, and energy consumption were used to analyse the routing protocols. Generic parameters used for simulation are given in Table 1.

Table 1. Simulation parameters [15], [28], [29]

Name of the parameter	Value	
Routing protocol	AODV, ACO	
Network simulator	MATLAB	
Area	1000*1000 m^2	
Grid/road	10	
Number of nodes	30	
Packet size	512 bytes	
Speed of vehicle	0-1 m/s	
Simulation	50 times	
Node placement	Random	
Propagation model	Two-ray ground reflection model	
Transmission energy (ETX)	50 nJ/bit	
Receiving energy (ERX)	50 nJ/bit	
Transmission amplification	Signal amplification factors of free space (εfs)	10 PJ/bit
	Signal amplification factors of multipath fading (εmp)	0.0013 PJ/bit
Data aggregation energy (EDA)	5 nJ/bit	
Initial energy (Eo)	1 J	
alpha (α)	1 J	
beta (β)	1 J	
Evaporation rate (ρ)	0.5	

7. METHOD ADOPTED

While creating the traffic scenario for both AODV and ACO, the total area is divided into 10 equal horizontal grids. Which have specified space for a vehicle to move. For implementation 30 vehicles are considered. The total number of vehicles is randomly divided into two parts, half of the vehicles moved toward the left-hand side, and the remaining half of the vehicles moved toward the right-hand side along x-axis. A random source node was selected from the bottom-most grid and a random destination node was selected from the topmost grid. The vehicle moves with a speed varying from 0-1 m/s.

Then AODV and ACO routing protocol enables the movement of nodes and selects the path between source and destination. A routing table that includes the source node, intermediate nodes, and destination node is maintained in the case of AODV. After the setup of the scenarios, the following QoS parameters are considered for the performance evaluation of both the AODV and ACO routing protocol.

- Throughput is the successful transmission of the data packet from the source to the destination. It is measured in kilobits transferred per second (Kbps) [12], [30], [31].
- Packet loss ratio is the ratio of the data packet sent to the packet received by the destination [24], [32], [33].
- Routing overhead is the measurement of the data packet received by a node, it may be a source node, intermediate node, or destination node [34].
- Delay is the time taken to deliver a data packet from source to destination [30].
- Energy consumption is calculated through the energy model [35], [36]. The energy consumption model adopts different path channels and it also depends upon the distance between the transmitter and the receiver:
  a. For the free space channel (εfs), energy consumption is d2
  b. For multipath channel (εmp), energy consumption is d4

To transmit a packet of n bits at a distance d, ETX is calculated through (5):

$$E_{TX} = \begin{cases} \text{n} * E_{elec} + \text{n} * \varepsilon\text{fs} * d^2 & \text{d} \leq \text{do} \\ \text{n} * E_{elec} + \text{n} * \varepsilon\text{mp} * d^4 & \text{d} > do \end{cases} \tag{5}$$

To receive a packet of n bits, ERX is calculated as (9):

$$E_{RX} = \text{n} * E_{elec} \tag{6}$$

Where threshold is:

$$do = \sqrt{(\varepsilon\text{fs}/\varepsilon\text{mp}} \tag{7}$$

Eelec is the electronic energy.

8. SIMULATION RESULTS

This section shows the results performed after the evaluation for both AODV and ACO routing protocol through the MATLAB simulator, after the establishment of the link between the source and destination node through intermediate nodes. We studied and observed the performance of AODV and ACO in terms of throughput, packet loss ratio, routing overhead, delay, and energy consumption.

Figure 3 shows the successful transmission of the packet that is, the value of throughput for AODV and ACO versus the number of times the route is found in the simulation area. It is clear from the graph that throughput for AODV is higher as compared to ACO for the different number of routes. ACO is a self-organization system in which different fitness functions like distance, delay, and speed of the vehicle are considered. Whereas AODV is based on the hop count between source and destination. The average value of throughput for AODV is 64.0017 Kbps, with a minimum value of 48.43 Kbps and a maximum value of 76.8 Kbps. The average value of throughput for ACO is 64.869 Kbps, with a minimum value of 49.62 Kbps and a maximum value of 77.04 Kbps.

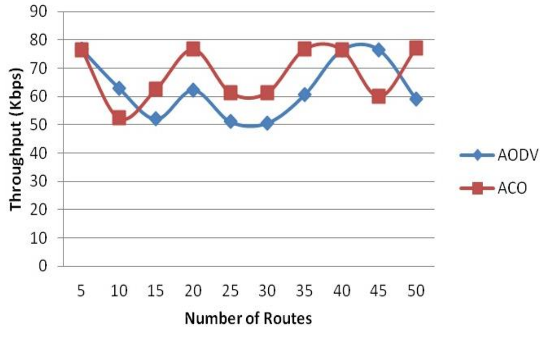

Figure 3. Throughput comparison between AODV and ACO

Figure 4 shows the ratio between the packet sent to the received, at the destination for AODV and ACO versus the number of times the route is found in the simulation area. The packet loss is less for AODV as compared to ACO for the different number of routes. The average value of the packet loss ratio for AODV is 0.295, with a minimum value of 0.155 and a maximum value of 0.467. The average value of packet loss for ACO is 0.286, with a minimum value of 0.152 and a maximum value of 0.454.

Figure 5 shows the overhead while sending the data packet from source to destination for AODV and ACO versus the number of times the route is found in the simulation area. The graph shows that the routing overhead is low for AODV as compared to ACO for the different number of routes. The average value of routing overhead for AODV is 70.40, with a minimum value of 53.28 and a maximum value of 84.48. The average value of routing overhead for ACO is 71.35, with a minimum value of 54.58 and a maximum value of 84.47.

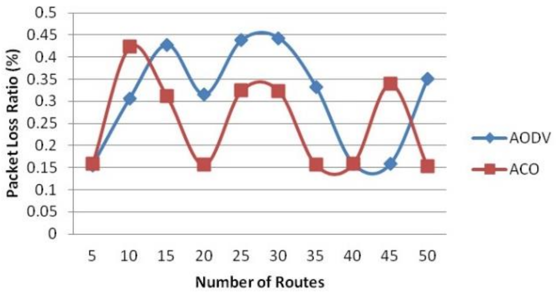

Figure 4. Packet loss ratio for AODV and ACO

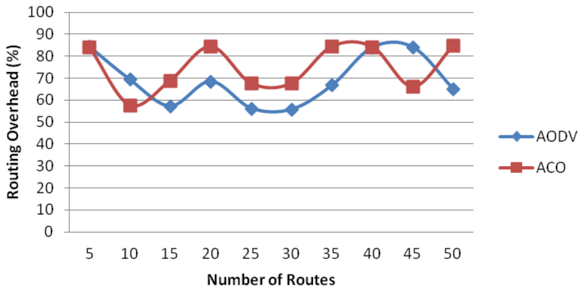

Figure 5. Routing overhead for AODV and ACO

Figure 6 shows the delay while sending a data packet from source to destination for AODV and ACO versus the number of times routes found during the simulation. The graph shows that there is very little difference between the delay for AODV and ACO. There is an average delay of 9.88 μs for AODV with a minimum value of 5.23 μs and a maximum value of 15.6 μs. The average value of delay for ACO is 9.56 μs, with a minimum value of 5.18 μs and a maximum value of 15.14 μs.

Figure 7 shows the energy consumption while sending a data packet from source to destination for AODV and ACO versus the number of times routes found during simulation. Energy consumption is calculated based on the transmission as well as receiving energy. The graph shows that AODV has less energy consumption while sending data packets as compared to ACO. While implementing AODV hop count is considered and while implementing ACO fitness functions like distance, delay, and speed of the vehicle are considered. The energy consumption for AODV is 0.289 J, with a minimum value of 0.292 J and a maximum value of 0.474 J. The average value of energy consumption for ACO is 0.357 J, with a minimum value of 0.189 J and a maximum value of 0.529 J. The average values of different parameters for AODV and ACO are given in Table 2.

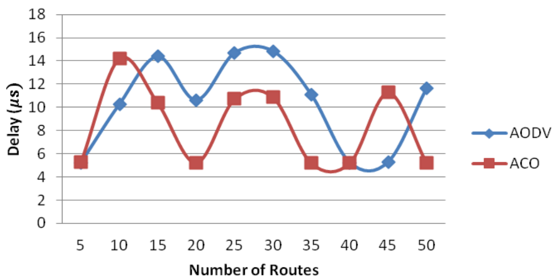

Figure 6. Delay in AODV and ACO

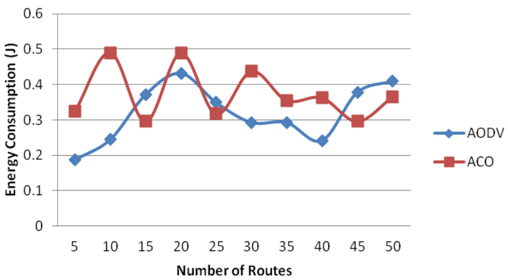

Figure 7. Consumed energy for AODV and ACO

Table 2. Average value of different parameters

S. No	Parameter	AODV	ACO
1	Throughput (Kbps)	64.001	64.869
2	Packet loss ratio (%)	0.295	0.286
3	Routing overhead (%)	70.40	71.35
4	Delay (μs)	9.88	9.56
5	Consumed energy (j)	0.289	0.357

9. DISCUSSION

To evaluate a VANET network there are n number of parameters. Such as throughput, latency, bandwidth, packet delivery ratio, packet collision rate, packet drop rate, throughput, packet loss ratio, and energy usage [23], [37], [38]. In this study, the following parameters are taken into consideration.

The throughput ‘Ť’ is the rate at which the data ‘D’ is transmitted in transmission time ‘ŧ’ over the communicating route. It is measured as the number of bits transmitted per second It is advantageous if the routing protocol has better throughput. It is represented as (8):

$$\check{T} = \frac{D}{ŧ} \quad (8)$$

The evaluation result of AODV and ACO are shown in section 9. It clearly shows that ACO is 1.35% better than AODV. Swarm intelligence is the foundation of ACO. It is modelled after how actual ants behave when trying to locate the shortest route to a food source. These bio-inspired networks have demonstrated greater results than AODV since they are dynamic and scalable [39].

The packet loss ratio is defined as the proportion of packets received to all packets sent during the transmission [40]. To compute the percentage, divide the packet loss ‘PL’ by the transmitted packet ‘TP’ and multiply the result by 100. It is represented as (9):

$$PLR = \frac{LP}{TP} * 100 \quad (9)$$

Section 9 displays the outcomes of the AODV and ACO evaluations. Due to the dynamic behaviour of ACO's route-finding strategy, there is reduced packet loss when compared to AODV. Because ACO selects more stable and reliable, it is evident that AODV experiences 3% greater packet loss than ACO [41].

Delay is the amount of time a data packet needs to travel from the sender (TS) to the intermediate nodes (TI), and then from the intermediate nodes to the receiver node (TD). It is embodied as (10):

$$D = T_S + T_I + T_D \quad (10)$$

The findings of the AODV and ACO evaluations for delay is presented in section 9. It clearly shows there is 3.5% less delay in ACO than AODV. The route-finding strategy of ACO makes it more suitable by reducing delay [42]. Energy consumption is the required energy for transmitting ‘E_{TX}’ and receive ‘E_{RX}’ the data packet from source to destination. It is represented as (11):

$$E = E_{TX} + E_{RX} \quad (11)$$

The results of the AODV and ACO's energy consumption evaluation are presented in section 9. ACO consumes 19% more energy than AODV. The intermediate nodes in AODV are primarily in charge of creating multi-hop environments. It tries to choose the route with the fewest hops possible while lowering the desired node energy level for packet transmission and reception [43]. Energy consumption can be compromised if the information is received with less delay and minimal loss of information.

10. CONCLUSION

Routing plays a major role in the connectivity of vehicles in VANETs. The important parameters for the transmission of packets in VANETs like throughput and packet delivery ratio are largely affected by the underlined routing algorithm. In this work, we have compared the performance of AODV and ACO on throughput, packet loss ratio, routing overhead, delay, and energy consumption by implementing in the same VANET scenario. MATLAB was used for simulating these protocols. Based on the results, it has been found that AODV is performing better for routing overhead and energy consumption. Whereas ACO has performed better in terms of throughput, packet loss ratio, and delay. AODV is a reactive routing protocol. The routing overhead is low therefore resulting in less energy consumption. ACO being the hybrid protocol gave a better result for throughput and delay but could not optimize the routing overhead and energy consumption in comparison to AODV. The routing protocols have been proposed and based on their performance evaluation there is a need for optimization. Hence the hybrid protocol needs to be suggested to enhance the performance of VANETs.

REFERENCES

[1] P. Pradhan, L. Costa, D. Rybski, W. Lucht, and J. P. Kropp, “A Systematic Study of Sustainable Development Goal (SDG)

Interactions," *Earth's Future*, vol. 5, no. 11, pp. 1169–1179, Nov. 2017, doi: 10.1002/2017EF000632.
[2] C. Kroll, A. Warchold, and P. Pradhan, "Sustainable Development Goals (SDGs): Are we successful in turning trade-offs into synergies?," *Palgrave Communications*, vol. 5, no. 1, p. 140, Nov. 2019, doi: 10.1057/s41599-019-0335-5.
[3] M. E. Kruk *et al.*, "High-quality health systems in the Sustainable Development Goals era: time for a revolution," *The Lancet Global Health*, vol. 6, no. 11, pp. e1196–e1252, Nov. 2018, doi: 10.1016/S2214-109X(18)30386-3.
[4] P. Kaushal, M. Khurana, K. R. Ramkumar, and V. Gandhi, "A Study on Routing Protocols of Vehicular Ad Hoc Network," *International Journal of Advanced Research in Engineering and Technology*, vol. 11, no. 12, pp. 2672–2686, 2020.
[5] S. Garg, D. Mehrotra, H. M. Pandey, and S. Pandey, "Accessible review of internet of vehicle models for intelligent transportation and research gaps for potential future directions," *Peer-to-Peer Networking and Applications*, vol. 14, no. 2, pp. 978–1005, Mar. 2021, doi: 10.1007/s12083-020-01054-6.
[6] B. Afshar-Nadjafi and A. Afshar-Nadjafi, "A constructive heuristic for time-dependent multi-depot vehicle routing problem with time-windows and heterogeneous fleet," *Journal of King Saud University - Engineering Sciences*, vol. 29, no. 1, pp. 29–34, Jan. 2017, doi: 10.1016/j.jksues.2014.04.007.
[7] P. Kaushal, M. Khurana, and K. R. Ramkumar, "*A Research Perspective of VANET Applications: A Review," in Emerging Technologies in Data Mining and Information Security*. in Lecture Notes in Networks and Systems. Singapore: Springer Nature Singapore, 2023, doi: 10.1007/978-981-19-4193-1.
[8] S. M. Al-Garni and A. ben Abdennour, "A Neural Network Based Traffic Flow Evaluation System for Highways," *Journal of King Saud University - Engineering Sciences*, vol. 20, no. 1, pp. 37–45, 2008, doi: 10.1016/S1018-3639(18)30854-7.
[9] Z. Lu, G. Qu, and Z. Liu, "A Survey on Recent Advances in Vehicular Network Security, Trust, and Privacy," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 2, pp. 760–776, Feb. 2019, doi: 10.1109/TITS.2018.2818888.
[10] P. Kaushal, M. Khurana, and K. R. Ramkumar, "A Systematic Review of Swarm Intelligence Algorithms to Perform Routing for VANETs Communication," *ECS Transactions*, vol. 107, no. 1, pp. 5027–5035, Apr. 2022, doi: 10.1149/10701.5027ecst.
[11] S. Yogarayan, S. F. A. Razak, A. Azman, M. F. A. Abdullah, S. Z. Ibrahim, and K. J. Raman, "A Review of Routing Protocols for Vehicular Ad-Hoc Networks (VANETs)," *2020 8th International Conference on Information and Communication Technology, ICoICT 2020*, vol. 5, no. 1, pp. 25–43, 2020, doi: 10.1109/ICoICT49345.2020.9166174.
[12] H. Saini and R. Mahapatra, "Implementation and Performance Analysis of AODV Routing Protocol in VANETs," *International Journal of Emerging Science and Engineering*, vol. 1, no. 2, pp. 24–29, 2014.
[13] S. Malik and P. K. Sahu, "A comparative study on routing protocols for VANETs," *Heliyon*, vol. 5, no. 8, p. e02340, Aug. 2019, doi: 10.1016/j.heliyon.2019.e02340.
[14] Z. Khan, S. Fang, A. Koubaa, P. Fan, F. Abbas, and H. Farman, "Street-centric routing scheme using ant colony optimization-based clustering for bus-based vehicular ad-hoc network," *Computers and Electrical Engineering*, vol. 86, p. 106736, Sep. 2020, doi: 10.1016/j.compeleceng.2020.106736.
[15] F. Aadil, K. B. Bajwa, S. Khan, N. M. Chaudary, and A. Akram, "Caconet: Ant colony optimization (ACO) based clustering algorithm for VANET," *PLoS ONE*, vol. 11, no. 5, p. e0154080, May 2016, doi: 10.1371/journal.pone.0154080.
[16] B. Manimekala, "Determining the Shortest Path Using Ant Colony Optimization (Aco) Algorithm in Vanet," *Dogo Rangsang Research Journal*, vol. 10, no. 7, pp. 49–53, 2020.
[17] H. P. Mistry and N. H. Mistry, "A survey: Use of ACO on AODV & DSR routing protocols in MANET," in *ICIIECS 2015 - 2015 IEEE International Conference on Innovations in Information, Embedded and Communication Systems*, IEEE, Mar. 2015, pp. 1–6, doi: 10.1109/ICIIECS.2015.7192953.
[18] C. Del-Valle-Soto, C. Mex-Perera, J. A. Nolazco-Flores, R. Velázquez, and A. Rossa-Sierra, "Wireless sensor network energy model and its use in the optimization of routing protocols," *Energies*, vol. 13, no. 3, p. 728, Feb. 2020, doi: 10.3390/en13030728.
[19] H. Zhang, X. Wang, P. Memarmoshrefi, and D. Hogrefe, "A Survey of Ant Colony Optimization Based Routing Protocols for Mobile Ad Hoc Networks," *IEEE Access*, vol. 5, no. 1, pp. 24139–24161, 2017, doi: 10.1109/ACCESS.2017.2762472.
[20] P. Waraich and N. Batra, "Performance Analysis of Ad hoc Routing Protocols over VANETs," *International Journal of Computer Applications*, vol. 147, no. 14, pp. 41–46, Aug. 2016, doi: 10.5120/ijca2016911277.
[21] Z. Rezaeifar, F. Hendessi, B. S. Ghahfarokhi, and T. A. Gulliver, "A Reliable Geocast Routing Protocol for Vehicular Ad Hoc Networks," *Wireless Personal Communications*, vol. 83, no. 1, pp. 281–295, Jul. 2015, doi: 10.1007/s11277-015-2393-3.
[22] M. Habib and R. K., "A Survey: Use of SDN on DSDV Routing Protocol in VANET," *International Journal of Scientific Engineering and Science*, vol. 1, no. 11, pp. 53–57, 2017.
[23] A. Ahamed and H. Vakilzadian, "Impact of Direction Parameter in Performance of Modified AODV in VANET," *Journal of Sensor and Actuator Networks*, vol. 9, no. 3, p. 40, Sep. 2020, doi: 10.3390/JSAN9030040.
[24] A. Silva, N. Reza, and A. Oliveira, "Improvement and Performance Evaluation of GPSR-Based Routing Techniques for Vehicular Ad Hoc Networks," *IEEE Access*, vol. 7, pp. 21722–21733, 2019, doi: 10.1109/ACCESS.2019.2898776.
[25] A. Mor, "A study of improved AODV routing protocol in VANET," *International Journal of Computer Applications and Information Technology*, vol. 2, no. 1, pp. 1–3, 2013.
[26] Nidhi, "Performance Evaluation of Realistic VANET Using Traffic Light Scenario," *International Journal of Wireless & Mobile Networks*, vol. 4, no. 1, pp. 237–249, Feb. 2012, doi: 10.5121/ijwmn.2012.4118.
[27] Y. Azzoug and A. Boukra, "Bio-inspired VANET routing optimization: an overview: A taxonomy of notable VANET routing problems, overview, advancement state, and future perspective under the bio-inspired optimization approaches," *Artificial Intelligence Review*, vol. 54, no. 2, pp. 1005–1062, Feb. 2021, doi: 10.1007/s10462-020-09868-9.
[28] T. Stützle and M. Dorigo, "ACO Algorithms for the Traveling Salesman Problem christopher jide," *Evolutionary algorithms in engineering and computer science*, vol. 4, no. 1, pp. 163–183, 2005.
[29] P. Mohanty and M. R. Kabat, "Energy efficient structure-free data aggregation and delivery in WSN," *Egyptian Informatics Journal*, vol. 17, no. 3, pp. 273–284, Nov. 2016, doi: 10.1016/j.eij.2016.01.002.
[30] M. Bhagyavathi and V. Saritha, "Energy and velocity-based multipath routing protocol for VANET," *International Journal of Advanced Intelligence Paradigms*, vol. 12, no. 3–4, pp. 239–253, 2019, doi: 10.1504/IJAIP.2019.098562.
[31] M. Khurana and C. R. Krishna, "MIMO-based spatial diversity scheme in VANET scenario," in *Proceedings on 2015 1st International Conference on Next Generation Computing Technologies, NGCT 2015*, IEEE, Sep. 2016, pp. 257–261, doi: 10.1109/NGCT.2015.7375122.
[32] T. S. Chouhan and R. S. Deshmukh, "Analysis of DSDV, OLSR and AODV Routing Protocols in VANETS Scenario: Using NS3," in *Proceedings - 2015 International Conference on Computational Intelligence and Communication Networks, CICN 2015*, IEEE, Dec. 2016, pp. 85–89, doi: 10.1109/CICN.2015.26.
[33] L. Shi, A. Fapojuwo, N. Viberg, W. Hoople, and N. Chan, "Methods for calculating bandwidth, delay, and packet loss metrics in multi-hop IEEE802.11 ad hoc networks," in *IEEE Vehicular Technology Conference*, IEEE, May 2008, pp. 103–107, doi: 10.1109/VETECS.2008.34.

[34] A. A. Mu'azu, L. T. Jung, I. A. Lawal, and P. A. Shah, "Throughput Measurement for the Guaranteed QoS Real-time Traffic Flows in VANETs," *Procedia - Social and Behavioral Sciences*, vol. 129, pp. 297–304, May 2014, doi: 10.1016/j.sbspro.2014.03.680.

[35] M. Rangchi and H. Bakhshi, "A new energy efficient routing algorithm based on load balancing for wireless sensor networks," in *2014 7th International Symposium on Telecommunications, IST 2014*, IEEE, Sep. 2014, pp. 1201–1205, doi: 10.1109/ISTEL.2014.7000886.

[36] J. S. Lee and C. L. Teng, "An Enhanced Hierarchical Clustering Approach for Mobile Sensor Networks Using Fuzzy Inference Systems," *IEEE Internet of Things Journal*, vol. 4, no. 4, pp. 1095–1103, Aug. 2017, doi: 10.1109/JIOT.2017.2711248.

[37] K. Priya and J. Malhotra, "Optimisation of MAC layer to mitigate the effect of increased mobility in VANET," in *Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics, IC3I 2016*, IEEE, Dec. 2016, pp. 623–628, doi: 10.1109/IC3I.2016.7918038.

[38] G. Li and L. Boukhatem, "Adaptive vehicular routing protocol based on ant colony optimization," in *VANET 2013 - Proceedings of the 10th ACM International Workshop on VehiculAr Inter-NETworking, Systems, and Applications*, New York, NY, USA: ACM, Jun. 2013, pp. 95–97, doi: 10.1145/2482967.2482971.

[39] A. M. Shaban, S. Kurnaz, and A. M. Shantaf, "Evaluation DSDV, AODV and OLSR routing protocols in real live by using SUMO with NS3 simulation in VANET," in *HORA 2020 - 2nd International Congress on Human-Computer Interaction, Optimization and Robotic Applications, Proceedings*, IEEE, Jun. 2020, pp. 1–5, doi: 10.1109/HORA49412.2020.9152903.

[40] A. R. Deshmukh, P. Nirmal, and S. S. Dorle, "A New Approach for Position Based Routing Protocols Based on Ant Colony Optimization (ACO) Technique in Vehicular Ad Hoc Network (VANET)," in *2021 International Conference on Intelligent Technologies, CONIT 2021*, IEEE, Jun. 2021, pp. 1–5, doi: 10.1109/CONIT51480.2021.9498332.

[41] A. W. Y. Khang *et al.*, "Qualitative-based QoS performance study using hybrid ACO and PSO algorithm routing in MANET," *Journal of Physics: Conference Series*, vol. 1502, no. 1, p. 012004, Mar. 2020, doi: 10.1088/1742-6596/1502/1/012004.

[42] H. Kadhim and M. A. Hatem, "Modification AODV Routing Protocol to Find Best Shortest Path Based on Parallel Modified ACO-DNN," in *2019 2nd International Conference on Engineering Technology and its Applications, IICETA 2019*, IEEE, Aug. 2019, pp. 196–201, doi: 10.1109/IICETA47481.2019.9012972.

[43] K. Sumathi and D. V. Kumar, "Energy-Efficient Perspicacious Ant Colony Optimization Based Routing Protocol for Mobile Ad-Hoc Network," *International Journal of Computer Networks and Applications*, vol. 9, no. 2, pp. 240–250, Apr. 2022, doi: 10.22247/ijcna/2022/212339.

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