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An Enhanced Bio-Inspired Routing Algorithm for Vehicular Ad Hoc Networks

Raghu Ramamoorthy[1,*] and Menakadevi Thangavelu[2]

[1]*Department of Computer Science and Engineering, The Oxford College of Engineering, Karnataka, India*
[2]*Department of Electronics and Communication Engineering, Adhiyamaan College of Engineering, Tamilnadu, India*

([*]Corresponding author's e-mail: raghuace85@gmail.com)

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Abstract

Vehicular ad hoc networks (VANETs) demands reliable communication mechanisms for time-critical communication between vehicles. In VANETs, communication links between vehicles are prone to frequent breaks due to high mobility and topology changes. In this context, this work presents an enhanced bio-inspired routing algorithm (EBIRA) to provide reliable communication. In EBIRA, enhanced ant colony optimization (EACO) finds the optimal long-life short-distance routes with the minimum hops based on distance, received signal strength metric, hop count, and evaporation rate. In EBIRA, the selected path has a short distance and a high level of connectivity at the link level with minimum hops. Choosing the shortest path through minimum hops with high connectivity level links improves route lifetime and reduces frequent link breaks between vehicles. Simulation results show that the performance of EBIRA is better than reliable route discovery by using ant colony optimization (RDACO) and road-aware geographic routing protocol (RAGR) in terms of packet delivery ratio, throughput, and latency. Furthermore, variations of the received signal strength based on vehicle density and speed are evaluated, and the EBIRA route discovery success ratio is estimated and shown based on vehicle density at speed.

Keywords: VANETs, Routing, Pheromone count, Optimal path, Reliable communication

Introduction

A vehicular ad hoc network (VANET) is a subcategory of a mobile ad hoc network (MANET). VANET [1] is an autonomous, decentralized, infrastructure-less, and self-configured network intended for time-critical communication and information sharing. VANET allows vehicles to communicate with other vehicles and nearby infrastructure (Vehicle-to-vehicle communication (V2V) and Vehicle-to infrastructure communication (V2I)). VANET provides a variety of services, including road safety (preventing crash and accident reporting), traffic management (traffic information exchange: Traffic congestion), and entertainment (video streaming and internet access). Being a subset of MANET, VANET does not rely on fixed infrastructure but faces high mobility. High mobility can lead to rapid topology changes, often disconnecting, and unsuccessful packet delivery. VANET routing faces various challenges due to its unique characteristics such as high mobility, dynamic topology, unlimited network size, no infrastructure, and wireless communication. VANET routing requirements are different from MANET [2] routing due to these unique characteristics. However, it is not enough to consider VANET specific characteristics alone to improve routing performance. Additionally, some parameters [3] such as received signal strength, nodes transmission, and receiving powers still need to be considered when designing a reliable protocol.

In this work, a bio-inspired algorithm such as ACO (ant colony optimization) is utilized to develop a reliable routing mechanism by considering VANET characteristics and additional parameters. Bio-inspired algorithms are robust and have specific strength to solve VANET routing problems to provide the best timely and reliable message delivery [4]. There are many merits of using bio-inspired algorithms in VANET routing. Bio-inspired algorithms are suitable for large-scale VANET networks because finding routes in VANET is similar to the natural way of finding routes by insects such as ants and bees. Ants and bees can quickly find a short path to their food sources without delay and congestion. The vital advantage of bio-induced algorithms is their low complexity [5]. Due to the limited computing capabilities of the vehicle, it is not easy to set up compute-intensive routing algorithms at the node level in VANET. Biological algorithms can perform routing tasks with less complexity. The adaptability and self-organizing characteristics of natural algorithms can cope with frequent topology changes. The robustness feature of the bio-inspired algorithm often helps to overcome network interruptions in the form of disconnections.

The obstacles in the road scenario can fade the transmission signals and raise frequent disconnections between vehicles. Therefore the reliable route must cope with frequent disconnections. Most routing protocols believe that the hop count [6] is an important metric to limit the length of the path and the packet transmission count. Hop count affects packet delivery ratio, throughput, delay, link connectivity, link reliability, and link lifetime. In the proposed work, we will rely on distance, received signal strength, and hop count to improve link connectivity, link reliability, and link lifetime. A weak signal between nodes imposes a high connectivity loss. The proposed model gives less and more credit to weak and strong signals in the form of pheromone quantity.

ACO is a bio-inspired algorithm [7] and is motivated by the natural behavior of ants. In the ACO, ants find the shortest route from their nest to the food source. Ants release pheromones in the path they travel. The pheromone density depends on the distance between the food source and the nest. The ants make the trip to the food source with the maximum pheromone concentration specified by the previous ants. Following the same route, the ants return to the nest from a food source by depositing a certain amount of pheromone depending on the evaporation rate. This idea is considered in the proposed work to find the optimal route between the origin and the destination. ACO is the most convenient biological algorithm for routing in VANET [8,9] due to the following reasons.

1) Scalability: ACO can generate several ants and adjust them according to network size. The ACO algorithm can create more ants to deal with the temporary network. Indirect communication between ants improves scalability.

2) Adaptation: Ants may find low QoS routes or high QoS routes, but the ACO is adaptable to frequent network changes. Ant behavior is deterministic. Ants can die or reproduce based on changes in the network topology.

3) Parallelism: In ACO, the routing mechanism functions distributed between all the ants. Ants can communicate with other ants in parallel to complete the routing task. Parallel communication improves the convergence speed of the algorithm.

4) Fault Tolerance: In ACO, the link disconnection does not end with catastrophic failures. ACO naturally follows a decentralized control approach. The absence of specific nodes or link breaks does not reduce routing performance.

5) Routing Similarity: The VANET communication scenario is similar to the ACO communication scenario. In VANET, all generated packets (control and data) intend to reach the destination by sharing routing tasks. Similarly, all the ants created in ACO share the routing task between them to find food sources without delay.

All of the above arguments prove ACO adaptability, robustness, and potential for use in VANET routing.

Recently, a bio-inspired algorithm like ACO has attracted researchers for 2 reasons. The first reason is the unique characteristics of ACO include self-organization, scalability, robustness, and adaptability [10]. The second reason is the similarity between the routing scenario in VANETs and the ACO communication scenario. ACO algorithm successfully applied to solve different optimization problems such as scheduling, assignment, telecommunication routing, and traveling salesman. The ACO adaptability, parallelism, and scalability characteristics increase its use to solve VANET routing problems [11,12]. A vast quantity of information is created and exchanged between moving communication entities over a network in the present era. A long-life stable shortest path is required to provide reliable data exchange between moving entities in networks. The long-life shortest path should cope with the challenge of dynamic topology as well as routing challenges. The main objective of the proposed model is to find a reliable long-life stable short path between source and target by dynamically estimating the pheromone value of the route. The dynamic parameters such as distance, received signal strength metric, hop count, and evaporation rate influences pheromone density on paths. In the proposed work, the pheromone concentration on the routes is constantly monitored and adjusted according to the distance, signal strength metric, evaporation rate, and hop calculation, which allows the selection of the optimal paths for efficient routing.

The significant contributions of the proposed work are generalized as follows:

1) The proposed work aimed to find an optimal long-life short-distance route with the least hops for routing packets between source and destination.

2) An enhanced ACO was adopted in the proposed model to find optimal long-life short-distance routes based on pheromone count.

3) The optimal route selection mechanism is adopted in enhanced ACO to select the long-life short-distance route with minimum hops to provide reliable data transmission.

4) An efficient route maintenance approach is added to the enhanced ACO to repair broken routes without delay.

5) Furthermore, the proposed EBIRA was compared with RDACO and RAGR against various parameters to prove its efficiency.

Related work

In this section, routing algorithms based on ant colony optimization are discussed. ACO-based algorithms are applied in a variety of ways to provide efficient data routing on VANETs. Many works [13-15] prove that ACO algorithms can find the optimal path among multiple paths or determine alternate routes during a route break. But the route lifetime and durability depend on essential metrics like nodes transmission power, received power, and received signal strength. In the proposed work, optimal paths are constructed based on pheromone count. The pheromone credited on routes based on distance, received signal strength metric, and hop count.

VANETs often face disconnection problems due to dynamic topological changes. Establishing a path through minimal hops and reliable links can reduce disconnection problems. In Chakroun *et al.* [16], the multi-metric unicast data-dissemination scheme (MUDDS) is proposed to establish dedicated routes. MUDDS calculates the link availability rate per link based on the hops count and packet reception rate. The hops count guarantees minimum hops on the path, and the packet reception rate guarantees link reliability. MUDDS aims to reduce disconnection problems. The efficient mobility-aware VANET routing using ACO (EMAVA) [17] is a position-based protocol proposed to find a reliable path to communicate with the destination. The EMAVA calculates trust value for an individual vehicle based on vehicle-related information such as distance, bandwidth, and speed. The optimization algorithm evaluates and selects the maximum trust value node to construct reliable paths. The significant features of ACO improve the EMAVA performance by choosing the optimal vehicle (highest trust value) with low computational efforts. Different traffic and mobility patents are considered in EMAVA to prove its scalability and reliability under different density and traffic variations.

The optimized node selection routing protocol (ONSRP) [18] is proposed to minimize frequent path disconnection and overhead issues in a high mobility environment. In ONSRP, each node maintains and updates routing tables with the received signal strength, estimated based on vehicle information such as distance, speed, direction, and trust value. Each node periodically exchanges hello messages to maintain the latest trusted values. ONSRP's optimized node selection procedure selects the most optimized vehicle with a high trust value and signal strength for packet routing. Kadhim *et al.* [19] introduced an AODV based efficient route selection method to select stable paths. In this method, the received signal strength between the nodes is measured to determine a more stable route. Nodes with high received signal strength participate in the path construction. Low signal strength degrades link quality and leads to link disconnection. In this work, the connectivity level of the link is improved by bringing high signal strength nodes in the path, and emergency messages are exchanged without delay.

The shortest-path problem is a significant optimization problem in traffic networks. To address the shortest path problem, Zhang *et al.* [20] introduced a novel ACO. In this work, a new pheromone-trail-model was used to deposit pheromone, and an orientation-guidance mechanism was used to guide the ants to find a short path. This work will find the shortest path to reduce travel time and guide customers to reach their destination quickly. Melaouene *et al.* [21] proposed an ACO-based algorithm to find the shortest path based on delay and hop count. For proactive search, it starts searching for an existing route through static nodes. It relies on ACO to initiate the reactive search. In a reactive search, the pheromone is credited on the path to find the shortest route. The shortest path is deposited with a high pheromone amount. This algorithm prevents the ACO from falling into the local - optimum problem depending on the evaporation operation. Furthermore, this ACO-based algorithm requires more performance in terms of overhead.

In Correia *et al.* [22], mobility aware ACO finds multiple shortest paths based on important vehicle information available in vehicular networks such as speed and location. In this algorithm, the evaporation rate is adjusted to vehicle speed and position to maintain stable attractiveness on the shortest paths. From multiple shortest routes, the roulette-wheel selection method selects the best route based on pheromone levels. Mohammadnia *et al.* [23] introduced an ACO-based load balancing system to build a load-balanced path for packet transmission. This approach relies on the AODV routing principle to provide robust communication over VANETs. The proposed method uses the explorer ant to create routes and search ant to find a specific destination. Through the selected shortest path, packets experience a minor delay. Kumar *et al.* [24] proposed ant colony-based dynamic source routing (ADSR) to prove ACO adaptability across various ad hoc networks. The ADSR is a combination of ACO and DSR (Dynamic source routing) protocols. The ADSR hybrid nature uses a proactive method for routing packets within the network and a reactive method for routing packets between networks. A combination of DSR with ACO reduces the route discovery overhead. The ADSR faces zone overlapping issues.

Silva *et al*. [25] proposed ACO-based AntRS to find the shortest paths based on hops count and Euclidean distance. AntRS agents select routes based on pheromone intensity, number of hops, and Euclidean distance. The agent ants update the pheromone on paths based on the evaporation rate to maintain stability in the routes. Similarly, agent ants update nodes routing tables to support a recent path when returning to the source. VANET often encounters disconnectivity issues. The AntRS selects paths with the lowest probability disconnect rate. The simulation results prove that the AntRS adaptable to various scenarios. Vijayalakshmi *et al.* [26] introduced the ACO-based energy-efficient routing algorithm to find the shortest and robust path. This algorithm relies on the Max-Min Path (MMP) mechanism to find optimal routes. This algorithm works in two phases. In the first phase, MMP is used to select relative paths. In the second phase, forward ants (FANTs) are transmitted in relative paths to choose the optimal shortest path. FANTs update the pheromone in each node as it travels, which helps the algorithm to select the optimal shortest path. Furthermore, the adaptive re-transmission approach of this algorithm effectively manages link failures. It detects the link break and finds new relative routes without delay.

An enhanced ad hoc on-demand distance vector (AODV) based ACO algorithm was proposed in Hao Dong *et al.* [27] to find the optimal routes. In the proposed algorithm, the path selection method of AODV is modified with ACO. The revised route selection mechanism relies on vehicle heuristics information such as speed and position to find more stable paths. Also, variations in pheromone evaporation rates were introduced into the route discovery mechanism to find more stable routes. Modifications to the ACO algorithm improve the efficiency of the network in the form of quick optimal route selection, reducing handoff frequency, and increasing route duration. Khoza *et al.* [28] present an enhanced hybrid ant colony optimization (IHACO) algorithm to select the best path for routing packets during peak rush hours. IHACO selects the best non-congested routes with the shortest travel time. IHACO is an enhanced version of the traditional ACO algorithm that integrates ACO with particle swarm optimization (PSO) and introduces quality of service to the intelligent transport system. At IHACO, the revised pheromone update model combines ACO and PSO pheromone update strategies to improve performance by establishing the best stable routes during the congested time. Initially, each road was assigned a random pheromone amount and updated dynamically to reflect traffic conditions. Considering the constant speed for all vehicles is IHACO's limit.

Datta *et al.* [29] proposed a reliable routing protocol based on a bio-motivated approach to select a stable route using hop count (HC), link quality (LQ), and route weightage factor (RWF). RWF is the level of visibility of a pheromone in a path that depends on the Euclidean distance. LQ specifies the stability level of the link based on the signal strength. HC refers to hops on the route. The optimal link has the highest optimum value (op value), which is calculated based on HC, LQ, CV (constant value), and RWF. The selected stable route has the lowest hops and the highest link quality. Oranj *et al*. [30] proposed a routing algorithm based on ACO and DYMO (Dynamic MANET On-demand) (ACO-DYMO) to perform routing in dynamic VANET environments. In ACO-DYMO, pheromone on the paths is deposited based on the transition probability rule and updated based on distance and path reliability. The routes identified by the discovery process are evaluated based on the delay time and route reliability to extend the route lifetime. This algorithm maintains frequently used roads by removing invalid routes according to the route duration or link lifetime. For each successful packet delivery, the route lifetime is extended based on the delay time and reliability. Ramamoorthy and Thangavelu [31] introduced an enhanced hybrid ACO protocol for the VANET environment to improve routing process efficiency. The protocol relies on source-based ACO and distance calculation methods to enhance routing process efficiency. It finds the shortest path with the least hops to data transfer between source and destination. The protocol convergence speed improved with dynamic parameters such as hops, distance, pheromone density.

Qureshi *et al.* [32] proposed distance and signal quality-aware routing (DSQR) to select the next hop for packet routing on VANETs. DSQR relies on distance, direction, and link quality to choose the best mid-area forwarder node towards the destination. Pythagoras theory is used to find the inter-vehicle distance. In DSQR, the quality of the link between nodes is estimated using the received signal strength and the average link quality. DSQR aims to provide the long duration shortest path between source and destination. Pheromone-based vehicle to vehicle (PBV2V) [33] routing is a bio-inspired vehicle to vehicle approach works based on the pheromones concept. At PBV2V, each vehicle maintains and transmits up-to-date information about their location and pheromone value to their one-hop neighbors using beacons from time to time. Pheromone strength reduced in frequently unused paths by using the concept of evaporation. In PBV2V, the optimal path is selected based on pheromone density. PBV2V reduces search time and overhead.

ACO-based delay-sensitive routing protocol [34] proposed to find reliable low end-to-end delay routes in VANETs. The transmission delay between 2 distinctive moving nodes is transformed as pheromone and considered input to pheromone deposit and evaporation models. The vehicle heuristic information such as distance, the expiration time of the link, and MAC backoffs are key metrics used to decide node connectivity and reliability levels. The positive feedback mechanism helps to select the subsequent forwarder nodes without delay. The dependency on frequently changing information such as transmission delay, distance, link lifetime, and MAC backoffs improves the adaptability of the proposed protocol for VANET environment changes. Dias *et al.* [35] introduced inverted ant colony optimization (IACO) to enable ants to choose the optimal route to their destination without traffic. IACO combines static and dynamic information to calculate route costs. The IACO treats route length as static information and vehicle density as dynamic information because vehicle density varies according to conditions. The IACO instructs vehicles to choose the route based on cost. High pheromone intensity on the road indicates a high cost.

The proposed model

This section presents enhanced ACO for optimal route selection in VANETs. The proposed EBIRA determines optimal long-life short-distance routes between source and destination with the least number of hops. To establish the optimal path, the enhanced ACO of the EBIRA depends on parameters such as distance (d_{xy}) between 2 vehicles [36,37], received signal strength metric ($rssm_K$) of the link, and hop count (HC_{xy}) that the packet has traveled. In the EBIRA, the distance between vehicles (d_{xy}) is computed and stored in the vehicle routing table (VRT) before starting the route construction mechanism. To find a new route, the route construction mechanism calls the route construction ants (RCAs) to calculate rss_{kd}, Tv_K, and $rssm_K$ and then the source broadcasts the route request ants (REQ-ANTs) in the network. Based on the analogy of traditional ACO, on the way to the destination, the REQ-ANTs deposits the pheromone on the route based on d_{xy}, $rssm_K$, and HC_{xy}. Similarly, the REP-ANTs (route reply ants) update pheromone in their route back to the source based on the evaporation rate, old pheromone value, distance and, hop count. The route with the highest pheromone density is considered for routing data packets between source and destination. The network in the EBIRA is called a graph (G) of V vehicles and L links between them. In the EBIRA, the route construction mechanism (RCM) relies on pheromone deposit and pheromone update models to find the optimal routes. The optimal route selection mechanism for data transmission depends on the pheromone count to select the optimal route for data transmission. The route maintenance mechanism relies on pheromone count and address stack to repair the broken route.

Pheromone deposit model

In the pheromone deposit model, the REQ-ANTs (Route Request Ants) deposit a certain amount of pheromone at each link by considering d_{xy} (Eq. (2)), $rssm_K$ (Eq. (5)), and HC_{xy} (Eq. (6)). The REQ-ANT relies on the VRT to find d_{xy} and $rssm_K$, and REQ-ANT's HC_{xy} field to find hop count. Consider there is a link between the x and y vehicles. The pheromone deposit model deposits pheromone on the link according to Eq. (1);

$$ph_{xy}^{k} = \frac{rssm_K}{HC_{x,y}} \times \frac{1}{d_{x,y}} \tag{1}$$

Where rss_{xy}, represents the received signal strength metric at vehicle y from vehicle x. HC_{xy} is the hops count that the REQ-ANT has traveled from the source to vehicle y via from vehicle z. Distance between vehicles x and y is d, and ph^{k}_{xy} is the pheromone deposited by K^{th} ant on link x,y.

Distance calculation scheme (DCS)

DCS's goal is to find the distance between 2 moving vehicles. The distance between 2 moving vehicles is the length of the link connecting the vehicles. The global position system (GPS) coordinates are used to find the Euclidean distance between vehicles. The Euclidean distance formula [38] is represented in Eq. (2);

$$d_{xy} = \sqrt{(p_2 - p_1)^2 + (q_2 - q_1)^2} \tag{2}$$

Where $(p_2 - p_1)$ and $(q_2 - q_1)$ represents the coordinates of the vehicles *x* and *y*. d_{xy} is the distance between 2 vehicles.

Received signal strength (rss_{kd})

The received signal strength [39] of the link indicates the reliability of the link. The *rss* at the receiver vehicle is calculated based on the *d* , G_E, G_T, and S_T. The *rss* of neighbor vehicle *k* from a distance *d* can be calculated as in Eq. (3);

$$rss_{kd} = \frac{G_E \times G_T \times S_T}{\left(4\pi \times d/\lambda\right)^2} \tag{3}$$

Where rss_{kd} is the received signal strength of the K^{th} vehicle from a distance '*d'*, G_E and, G_T is the receiving and transmitting antenna gains. S_T represents the transmitting antenna transmission power, *d* is the distance, and λ indicates wavelength utilized in VANET.

The threshold value of rss_{kd}

Tv_K is the threshold value of *rss* of K^{th} neighbor vehicle. Tv_K is calculated as in Eq. (4);

$$Tv_K = \frac{G_E \times G_T \times S_T}{\left(4\pi \times 0.9054r / \lambda\right)^2} \tag{4}$$

where *r* is the range of the antenna.

Received signal strength metric ($rssm_K$)

A vehicle can compute *rssm* value for K^{th} link with K^{th} neighbor vehicle as in Eq. (5);

$$rssm_k = \begin{cases} 0 & if\ rss_{kd} < Tv_K \\ \left(1 - \dfrac{Tv_K}{rss_{kd}}\right) & if\ rss_{kd} \geq Tv_K \end{cases} \tag{5}$$

Here $rssm_k$ is the received signal strength metric of the K^{th} link. If *rss* is less than the threshold value, then $rssm_K$ value is zero (low = 0). If *rss* is greater than or equal to the threshold value, then $rssm_K$ value is one (high = 1).

Hops count (HC_{xy})

The HC_{xy} indicates the hop count that the packet visited. Initially, the *HC* is set to zero and incremented by 1 when the packet starts leaving the vehicle. The *HC* is computed as in Eq. (6);

$$HC_{xy} = HC + 1 \tag{6}$$

Pheromone update model

The pheromone update model updates the pheromone on each link. Due to mobility, vehicles frequently change their location, resulting in a change in distance. The vehicles processing REQ-ANTs are in different positions when processing REP-ANTs, which affects the connectivity level of the link. Hence modifications are necessary to maintain stable attractiveness on links to select the regular routes. The REP-ANTs (route reply ants) take the responsibility of updating pheromones based on the evaporation rate, old pheromone value, hop count, and distance. The destination initiates REP-ANTs for all REQ-ANTs. The REP-ANTs reach the source based on the address stack of REQ-ANTs. The primary purpose of this model is to maintain a constant attraction in the paths. Eq. (7) shows the mathematical formula of the pheromone update model.

$$nph_{x,y}^{k} = \left(ph_{x,y} - \rho \right) ph_{\ x,y} \times HC_{xy} + \frac{1}{d_{x,y}} \tag{7}$$

where $nph^{k}_{x,y}$ is the new pheromone deposited by route reply ants. $Ph_{x,y}$ is the old pheromone value of that existing link. The link evaporation rate is ρ. Distance is represented as $d_{x,y}$. HC_{xy} is the hop count.

EBIRA routing process

The EBIRA routing process involves three mechanisms: Route construction mechanism (RCM), optimal route selection mechanism for data transmission (ORSMFDT), and route maintenance mechanism (RMM). **Figure 1** illustrates the routing procedure of EBIRA. If the source does not have a valid path, it transmits RCAs to calculate rss_{kd}, $Tv_{K,}$ and $rssm_K$ to find a new route before this d_{xy} is calculated. Vehicles discard duplicate RCAs and computed values stored in the VRT. Next, the source calls route construction mechanism. This mechanism collects the route information through REP-ANTs. Finally, the source analyses all received REP-ANTs to execute the route selection mechanism to find the optimal route. The route selection mechanism copies $Inter_{adds\ stack}$ of REP-ANT to DT-ANTs for data transmission. For handling link failures, the EBIRA calls case 1 or case 2.

Route construction mechanism (RCM)

When source *S* wants to send data to the destination *D*, it starts searching for a route to *D*. If the path is available, *S* sends the data to *D*. If the path is not available, *S* will begin to find a new path using RCM. The RCM calls a route initialization process to initialize a new route construction. In the route initialization process, every vehicle broadcasts a route construction ants (RCA) containing its vehicle identity (V_{id}), the distance between itself and neighbor (d_{xy}), antenna gain, maximum transmission power and, a sequence number (*Seq_No*) to their one-hop neighbor vehicles.

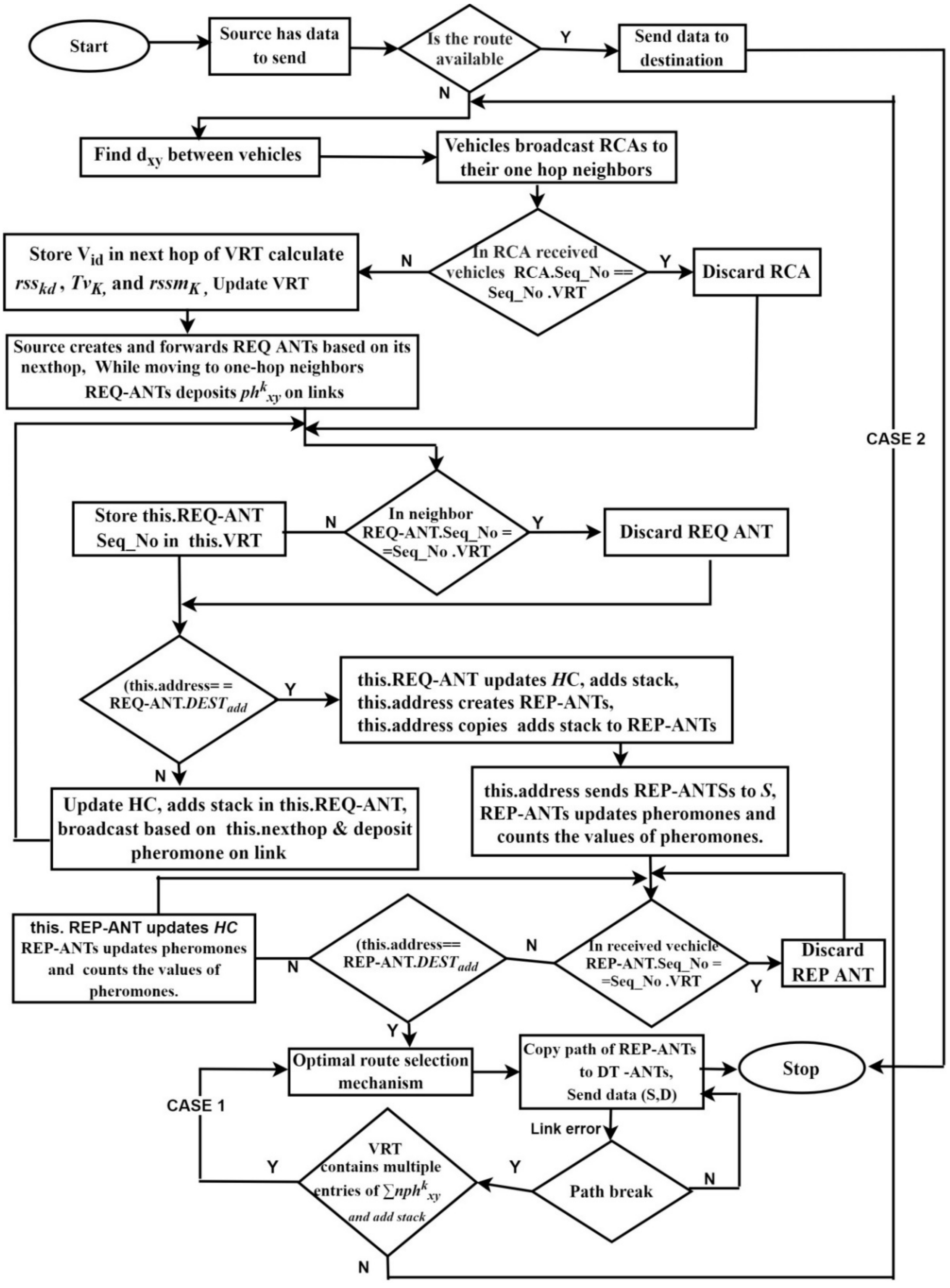

Figure 1 Flowchart of EBIRA.

Table 1 shows the structure of the RCA. **Table 2** represents the algorithm of the route initialization process.

Table 1 Route construction ant format.

V_{id}	*Antenna Gain*	*Maximum Transmission power*	d_{xy}	*Seq_No*

Before the RCA is transmitted, each vehicle calculates the distance d_{xy} using Eq. (2). The vehicles compare *Seq_No* of RCA's with *Seq_No* of VRT for verification. If verification is non-successful, the sender vehicle identity (V_{id}) is stored in the vehicle *Next Hop* field. Next, the vehicle extracts antenna gain and the maximum transmission power of a neighbor vehicle to calculate rss_{kd}, $Tv_{K,}$ and $rssm_K$ using Eqs. (3) - (5). The vehicle ignores the RCA if the verification is successful. Further, the vehicle waits to receive REQ-ANTs for successful and non-successful verification. **Table 3** represents the VRT. Every vehicle contains a VRT table.

Table 2 Algorithm of the route initialization process.

```
Algorithm: Route initialization process
Send_data (S, D)// S and D is the source and destination
{
    if (S.VRT !=0)      // VRT ≠ 0 represents entry for D is available in VRT of S.
        Send data to D;
    else
        S and intermediate vehicles broadcast RCAs to their one-hop neighbors;
At RCA received vehicle:
    if (this.Seq_No = Seq_No .VRT)   // Discard RCA by verifying Seq_No for second time
                                     // this.Seq_No represents the Seq_No of current RCA
    Discard RCA;                     // Seq_No .VRT is the Seq_No available in VRT
        Vehicle waits to receive REQ-ANTs;
    else
        Store this. V_id in Next Hop of VRT;
            Extracts d_xy, Antenna Gain, and Maximum Transmission power from RCA;
            Calculate rss_kd, Tv_K, and rssm_K;
            UpdateVRT;
            Vehicle waits to receive REQ-ANTs;
}
```

Table 3 Vehicle routing table (VRT).

V_{id}	*Seq_No* 1..n	$rssm_K$ 1..n	ph^k_{xy} 1..n	nph^K_{xy} 1..n	ρ 1..n	Σnph^K_{xy} 1..n	*Next Hop* Addresses 1..n	d_{xy} 1..n

In **Table 3**, V_{id} represents vehicle identity, *Seq_No* field represents sequence numbers, $rssm_K$ is received signal strength metric of a link which exists between itself and neighbors, ph^k_{xy} is the pheromone deposited by REQ-ANTs, nph^k_{xy} is the pheromone deposited by REP-ANTs, ρ is the evaporation rate of its links, *Next hop* is the list of one-hop neighbors of vehicles, $\sum nph^k_{xy}$ is the pheromone count and it stores the pheromone count value regarding path from destination to the current vehicle. d_{xy} specifies the distance itself and its neighbors.

After calculating rss_{kd}, $Tv_{K,}$ and $rssm_K$ the RCM generates REQ-ANTs at the source vehicle based on its *Next-hop* of VRT and starts finding an optimal route from source to destination through intermediate vehicles. The vehicle that creates or forwards REQ-ANTs includes their identities in the

REQ-ANT $Inter_{adds\ stack}$ and increments the *HC* value of REQ-ANTs by 1. The REQ-ANTs refer *Next hop* of vehicles to visit neighbors. While visiting neighbor vehicles, the REQ-ANTs deposit pheromone (ph^k_{xy}) on links that exist between itself and neighbors using the pheromone deposit model. $Inter_{adds\ stack}$ of REQ-ANTs contains identity details of visiting vehicles. Eq. (1) represents how REQ-ANTs deposit pheromone on links. When the neighbor vehicles receive REQ-ANT, it verifies the *Seq_No* of REQ-ANT with *Seq_No's* of its routing table. The neighbor discards duplicate REQ-ANT by comparing *Seq_No*s and waits to receive the next REQ-ANT. If the REQ-ANT is not discarded, the neighbor stores *Seq_No* in its routing table and verify whether it is the destination vehicle. If it is not the destination vehicle, then it forwards REQ-ANT to its neighbors based on its VRT's *Next hop*. While forwarding the REQ-ANT, the vehicle performs certain tasks such as adding its identity to $Inter_{adds\ stack}$ of REQ-ANT, updating hop count (HC) of REQ-ANT, and updating Ph^k_{xy} field in its VRT. All the neighbors follow the same activity if they are not destination vehicles. If the neighbor is the destination vehicle, it will start the REP-ANT towards the source. The destination vehicle generates REP-ANTs for each REQ-ANT. The destination adds its identity to $Inter_{adds\ stack}$ of REQ-ANT. $Inter_{adds\ stack}$ of REQ-ANTs copied to REP-ANTs. REP-ANTs follow $Inter_{adds\ stack}$ to reach the source from the destination. The intermediate vehicles discard the REP-ANTs by comparing *Seq_No's* or forwards according to $Inter_{adds\ stack}$ to neighbors if it is not a destination. If discarding is done based on *Seq_No's,* then the vehicle waits to receive the next REP-ANTs. While forwarding, the REP-ANTs updates its *HC*, nph^k_{xy} on links, and $\sum nph^k_{xy}$ in *RTV*; this activity is repeated until finding the source. REP-ANTs follows its $Inter_{adds\ stack}$ to reach *S.* The REP-ANTs maintain the stability of links by depositing pheromone (nph^k_{xy}) using the pheromone update model. Suppose the REP-ANT receiving node is the destination (source), then the optimal route selection mechanism is executed to find the optimal route. Eq. (7) represents the pheromone update model.

Table 4 REQ-ANT format.

Ant- Type	*Seq_No*	SRC_{add}	$DEST_{add}$	HC_{xy}	$Inter_{adds\ stack}$ *Address 1,2,3,…,n*

Table 5 REP-ANT format.

Ant- Type	*Seq_No*	SRC_{add}	$DEST_{add}$	HC_{xy}	$Inter_{adds\ stack}$ *Address 1,2,3,…,n*	$\sum_{1..n} nph^{K1}_{xy}$

Tables 4 and **5** shows the REQ-ANT and REP-ANTs format. Where *Ant- Type* specifies the type of ant created (REQ-ANT and REP-ANT), *Seq_No* is the sequence number used to avoid multiple broadcasting of the same packet, SRC_{add} and $DEST_{add}$ represents the source and destination addresses, HC_{xy} is the hop count that REQ-ANT and REP-ANT traveled, intermediate vehicle address stack ($Inter_{adds\ stack}$) stores and represents the travel history of REQ-ANT and REP-ANT. $\sum nph^{k1}_{xy}$ is the pheromone count. It stores the pheromone count value regarding the path from the destination to the source vehicle. **Table 6** represents the route construction mechanism algorithm.

Table 6 Route construction mechanism algorithm.

Algorithm: Route construction mechanism

- *a.* *S* creates REQ-ANTs based on its *Next Hop of VRT;*
- *b.* *S* includes its address in $Inter_{adds\ stack}$ of REQ-ANTs;
- *c.* *S* updates hop count in REQ-ANTs;
- *d.* *S* broadcasts REQ-ANTs to its one-hop neighbors based on its next hop;
- *e.* While moving to one-hop neighbors, REQ-ANTs deposits pheromones (ph^k_{xy}) on links;

On visit: Neighbors or Destination Receive_ REQ-ANTs;

```
{
if (this.Seq_No = Seq_No .VRT)   // this.Seq_No represents the  Seq_No of REQ-ANT
 Discard REQ-ANT;                // Seq_No .VRT is the Seq_No available in VRT
```

```
else
        Store this.REQ-ANT Seq_No in this.VRT; // this.VRT is the VRT of the current vehicle
    if (this.address= REQ-ANT.DEST_add) // this.address is the address of current vehicle
            update hop count at this.REQ-ANT;
            REQ-ANT deposits pheromone (Ph^k_xy);
            this. address includes its address in Inter_adds stack of REQ-ANTs;
        this. address creates REP-ANTs for each REQ-ANTs;
            this. address copies Inter_adds stack of REQ-ANTs to REP-ANTs and sends to S;
      else
          update hop count at this.REQ-ANT;
          this. address includes its address in Inter_adds stack of REQ-ANTs;
          this.address broadcasts REQ-ANTs to its neighbors based on its next hop;
          REQ-ANTs follow step e;
On visit towards to S :
    REP-ANTs follows their Inter_adds stack to reach S;
            if (this.Seq_No = Seq_No .VRT) // this.Seq_No represents the Seq_No of REP-ANT
               Discard REP-ANT;              // Seq_No .VRT is the Seq_No available in VRT
               Vehicle waits to receive next REP-ANTs;
            else
                 if (this.address= REP-ANT.DEST_add) // this.address is the current vehicle address
                          Execute optimal route selection mechanism;
                 else
                          this. REP-ANT updates HC;
                          REP-ANTs updates pheromones (nph^k_xy) on links;
                          REP-ANTs counts the value of pheromones (∑nph^k1_xy) from D to S;
                          REP-ANTs follows their Inter_adds stack to reach S;
}
```

Optimal route selection mechanism for data transmission (ORSMFDT)

After receiving the REP-ANTs, the source will find the optimal route using the optimal route selection mechanism. The ORSMFDT in the source selects the path with the highest pheromone count for data transmission. After the path is selected, DT-ANTs (Data Transfer Ant) can send the data to the destination. **Table 7** shows the DT-ANT format. **Table 8** shows the optimal route selection mechanism for data transmission.

Table 7 DT-ANT format.

Ant- Type	*Seq_No*	SRC_{add}	$DEST_{add}$	*Data*

Ant- Type specifies the type of ant created (DT- ANT), *Seq_No,* SRC_{add}*, and* $DEST_{add}$ is similar to REQ-ANT. *The data* part holds information that needs to be sent from source to destination.

Table 8 Optimal route selection for data transmission.

```
Algorithm: Optimal route selection for data transmission
At Source vehicle:
Source vehicle receives REP-ANTs {
Selects the high pheromone count REP-ANT;
Path = max (∑nph^k1_xy);
Copy path of REP-ANT to DT-ANTs;
Send data (S, D) through DT-ANTs ;
}
```

Route maintenance (RM)

Due to the high mobility of vehicles, the VANET is often prone to frequent disconnection. High mobility may cause frequent interruptions in data transmission. Path instability due to route intervals increases packet loss and delay. In this work, we assume that links or route failure often occurs due to the movement of vehicles from the routing activity or the loss of radio communication links between vehicles. The route maintenance mechanism handles the route breaks effectively. The destination sends the acknowledgments to the source for each packet received. If the destination fails to send the receipt to the source, then the source assumes that the link failure occurred in the established path. The RM mechanism handles route failure in 2 ways.

Case 1: In this case, the source receives multiple REP-ANTs during route construction, contains multiple pheromone counts ($\sum nph^k_{xy}$), and multiple addresses in the address stack of VRT for source to destination. In this case, the source calls an optimal route selection mechanism to select the optimal route based on $\sum nph^k_{xy}$ and address stack for handling link failure.

Case 2: In this case, we assume the source VRT lacks multiple entries for $\sum nph^k_{xy}$ and address stack. In this case, the source calls route construction and optimal route selection mechanism to find a new route.

Simulation environment and performance parameters

Simulation environment

This section describes the simulation environment. The proposed EBIRA is simulated in network simulator (NS2) according to **Table 9**. This section also describes RSS levels and route discovery success ratios with different vehicle densities and speeds. The road scenario is created using SUMO (Simulation of urban mobility). The maximum number of vehicles considered for simulation is 200 with variations (100, 120,140,160,180 and 200). The vehicle communication range is 250 m. We use a transmission range of 250 meters because it is the most efficient transmission range for dedicated short-range communication (DSRC). Vehicles follow CBR (constant bit rate) traffic to produce packets. Each packet size is 512 bytes. In EBIRA, vehicles move at a maximum speed of 30 m/s according to the car-following model. The free space propagation model was used in the simulation to calculate received signal strength (RSS). RSS is calculated based on transmission power, antenna gain, and distance between transmitter and receiver.

Table 9 Simulation parameters.

Simulation parameters	Values
Simulation Time	250 s
Simulation area	500×1000 m^2
Traffic model	CBR (Constant Bit Rate)
Transmission range	250 m
Data packet size	512 byte
Mobility model	SUMO
MAC protocol	IEEE 802.11p
Link bandwidth	1 Mbps
Number of vehicles	100 - 200
Vehicles speed	0 - 30 m/s
Evaporation rate	ρ = 0, 0.1, 0.12, 0.15, 0.19, 0.20, and 0.10
Simulator	NS2

In VANETs, link stability changes unpredictably. On-demand routing protocols [40] can provide reliable paths to cope with changes. Enhanced ACO’s pheromone models in the on-demand EBIRA are modified to maintain stability on links to cope with changes. In the proposed model, the new pheromone models were configured for different evaporation rates (0, 0.1, 0.12, 0.15, 0.19, 0.20 and 0.10) to verify the stability of the links under different conditions. In the simulation, 100-200 vehicles with varying evaporation rates are used to verify the efficiency of EBIRA. **Table 9** represents the simulation parameters of EBIRA.

Performance parameters

This section presents the performance parameters used to evaluate EBIRA. To compare the performance of EBIRA against Reliable route discovery by using ant colony optimization (RDACO) [41] and Road aware geographic routing protocol (RAGR) [41,42] following performance metrics are considered. Furthermore, variations of the received signal strength in EBIRA based on vehicle density with speed and the EBIRA route discovery success ratio based on vehicle density with speed are estimated and shown.

Packet delivery ratio (PDR)

PDR is the ratio of the total number of packets received in the destination vehicle to the total number of packets sent by the source vehicle. PDR is computed via Eq. (8);

$$PDR = \frac{\sum_{k=1}^{n} Packets\,received}{\sum_{k=1}^{n} Packets\,sent} \tag{8}$$

Throughput (T)

Throughput indicates the total number of bits received for the time 't' at the destination vehicle. Throughput is calculated via Eq. (9);

$$T = \frac{\sum_{K=1}^{n} Bits\,received}{t} \tag{9}$$

Latency (L)

Latency (L) refers to the average time taken by packets to reach their destination (D). L is calculated using parameters such as the arrival and start time of the packets. Eq. (10) shows the formula used in latency calculation.

$$L = \sum \left(Packets\,arrival\,time - Packets\,start\,time \right) \tag{10}$$

Results and discussion

This section presents the performance evaluation of EBIRA against RDACO and RAGR. Table 10 shows the comparison of EBIRA with RDACO and RAGR. Srivastava *et al*. [41] proposed RDACO to provide reliable communication for VANET environments. In RDACO, ACO uses forward and backward ants to select the right path by satisfying specific parameters such as delay and stability. Forward ants iteratively construct the optimal routes by traveling based on vehicle availability within the request range. When finding a route, forward ant deposits pheromone on a link based on link stability. The role of the forward ants ends after reaching the destination within the pre-defined delay limit. Then the destination converts all valid forward ants into backward ants and sends them back to the source through the same hops. On the way back through the specified hops, the backward ants update the pheromone by considering the evaporation rate and the old pheromone value. Once the backward ants reach the source, the source selects the most stable path based on the similarity between the forward and backward ant's visited hops. The chosen path is more stable because it has higher pheromone density and a minimum delay. Weights are assigned to routes based on stability, hop count, and delay. The path with the highest weightage is considered for data transmission

Qureshi *et al.* [42] introduced a new road-aware geographic routing (RAGR) to forward data packets to the destination in a VANET environment. RAGR depends on crucial parameters such as direction, traffic density, and distance to forward the packets. RAGR works and switches between 2 modes based on the position of the forwarder. In the first mode, the vehicle transforms into the next hop if it is in the middle of the transmission range, between the intersections, and heading towards the destination. If the forwarder is present at the intersection, then in the second mode, the highest weighted path is selected based on traffic density, direction, and distance to transmit the packets. The RAGR gives better performance in dynamic VANETs.

Table 10 Comparison of EBIRA with RDACO and RAGR.

Protocols	RDACO [41]	RAGR [41,42]	Proposed EBIRA
Methodology	Ant colony optimization	Geographical based routing	Enhanced ant colony optimization
Design Goal	To find a stable route with minimum delay and hop count.	To find the shortest path	To find optimal long-life short-distance routes with the least number of hops.
Forwarding Strategy	ACO based forwarding	Improved Greedy based forwarding	Enhanced ACO based forwarding
Path selection strategy	Requested Zone, hop count, and delay.	Distance, direction, traffic density	Distance, received signal strength metric, hop count, and evaporation rate.
Path setup	Yes	No	Yes
Frequent path disconnection	Low	High	Low
Simulator	NS2	NS2	NS2

Packet delivery ratio with different vehicle densities at different speeds

The packet delivery ratio (PDR) performance of the proposed EBIRA is estimated according to Eq. (8) in the presence of different vehicle densities at different speeds. Results show that EBIRA outperforms RDACO and RAGR. Choosing the optimal long-life short-distance route with a minimum number of hops improves PDR in EBIRA. The path selection strategy metrics such as distance (d_{xy}), received signal strength metric ($rssm_k$), hop count (HC_{xy}), and evaporation rate in EBIRA support to increase PDR performance. RAGR relies on significant metrics such as distance, direction, and traffic density to find optimal paths. Path selection by these key metrics does not provide optimal connectivity in all situations and successful delivery of all packets. In EBIRA, the connectivity level of the link depends on the $rssm_k$. Links with high signal strength levels have a high connectivity level and are credited with high pheromones. The signal strength levels of the vehicles vary depending on the circumstances. A long link between vehicles has low signal strength levels and is not allowed to participate in the routing.

Similarly, the short length link is deposited with high pheromone. EBIRA relies on signal strength to provide long-term optimal connectivity, d_{xy} to shorten the path, and HC_{xy} to limit hop count. Forwarding the packets through the available long-life shortest route with the least hops on low disconnectivity improves PDR in EBIRA. In RDACO, the stability of the link is calculated based on the position, velocity, and direction of the nodes. The node in the middle of the transmission range with low speed is considered as the most suitable forwarder node for forwarding packets to the destination. The source chooses a consistent path based on the similarity between the forward and backward ants visited hops. This option improves RDACO's PDR. But in EBIRA, a more stable route than RDACO is dynamically selected based on pheromone count. The pheromone count calculation of the backward ant of EBIRA is based on dynamic parameters called old pheromone value, evaporation rate, distance, and hop count. Dynamic parameters help EBIRA to choose a more consistent path than RDACO and lead to improvements in PDR. **Figures 2** and **3** show the PDR of EBIRA, RDACO, and RAGR for different vehicle variations at different speeds.

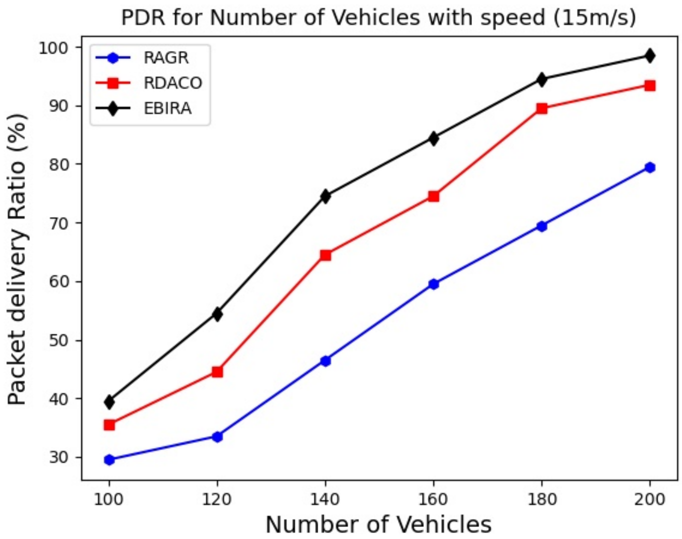

Figure 2 Packet delivery ratio based on the number of vehicles and speed (15 m/s).

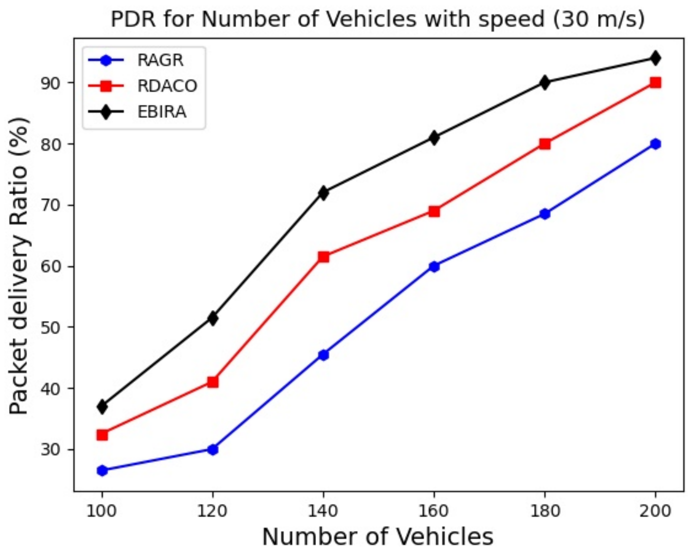

Figure 3 Packet delivery ratio based on the number of vehicles and speed (30 m/s).

Throughput with different vehicle densities at different speeds

Long length paths reduce the efficiency of the routing mechanism in the form of throughput [43]. According to the simulation results, EBIRA shows better throughput than RDACO and RAGR. The throughput is calculated according to Eq. (9). The reason for the improvement in throughput in EBIRA is the selection of a long-life short-distance route with a low number of hops for different vehicle densities at different speeds. RAGR frequently switches to store-carry forward mode to handle route disconnections. Frequent path disconnections in RAGR increase store-carry forward, resulting in automatic packet loss based on the packet frame time. The path disconnections in EBIRA avoid the regular establishment of new routes. Instead of building new routes, EBIRA relies on a route maintenance mechanism to prevent packet loss by maintaining reliable paths after route breaks. The route maintenance mechanism in EBIRA supports a short-distance route with a small number of hops after a path break to improve throughput. In RDACO, nodes in the middle of the transmission range are selected for packet routing. These chosen nodes have high availability and often reduce path breaks. But in general, the long-term use of paths in ACO-based algorithms produces a stagnation problem. The stagnation issue degrades the throughput by introducing congestion in routes. In EBIRA, the stagnation problem is solved by modifying the EACO pheromone deposit model based on a node parameter called distance. **Figures 4** and **5** represent the throughput performance of the proposed algorithm based on the number of vehicles at different speeds with existing methods.

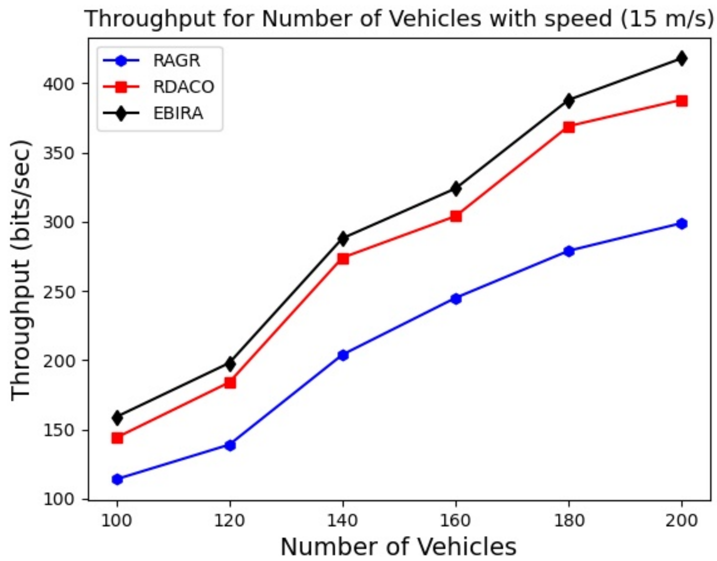

Figure 4 Throughput based on the number of vehicles and speed (15 m/s).

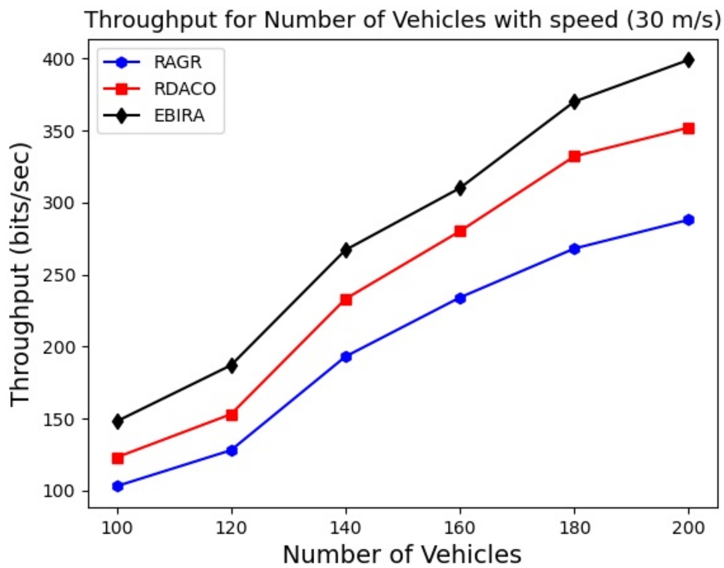

Figure 5 Throughput based on the number of vehicles and speed (30 m/s).

Latency at different vehicle densities at different speeds

In EBIRA, variations in vehicle density do not increase the latency. Routing packets over a short-distance route with a small number of hops reduce the latency in EBIRA. The latency in EBIRA is calculated based on Eq. (10). In RAGR, the lack of a suitable forwarder and the search for a right forwarder with random time increases the latency. In EBIRA, the shortest route with the least number of hops is built and available before the data transmission, so packets rely on the shortest route with the least hops between source and destination to reach the goal in the shortest time. In EBIRA, multiple shortest routes are maintained at the source routing table to select the second-best alternative path based on pheromone counts after route break without latency. The route established after route break has the shortest distance with the least hops, which reduces latency.

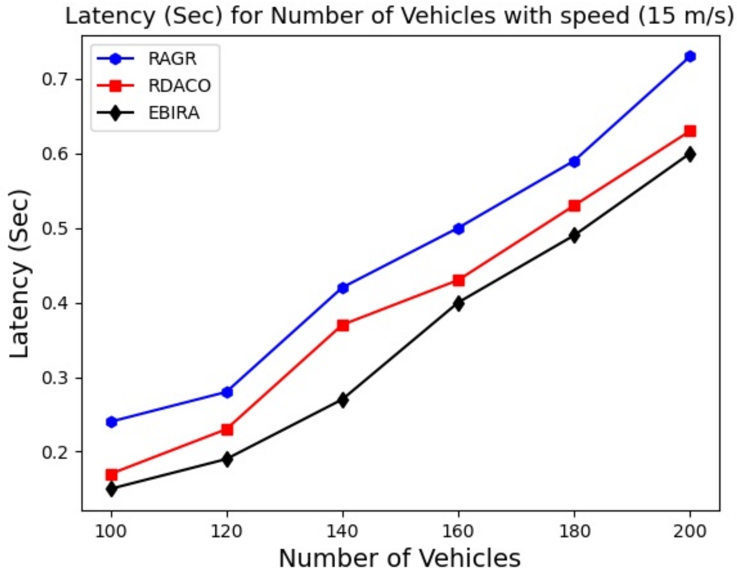

Figure 6 Latency based on the number of vehicles and speed (15 m/s).

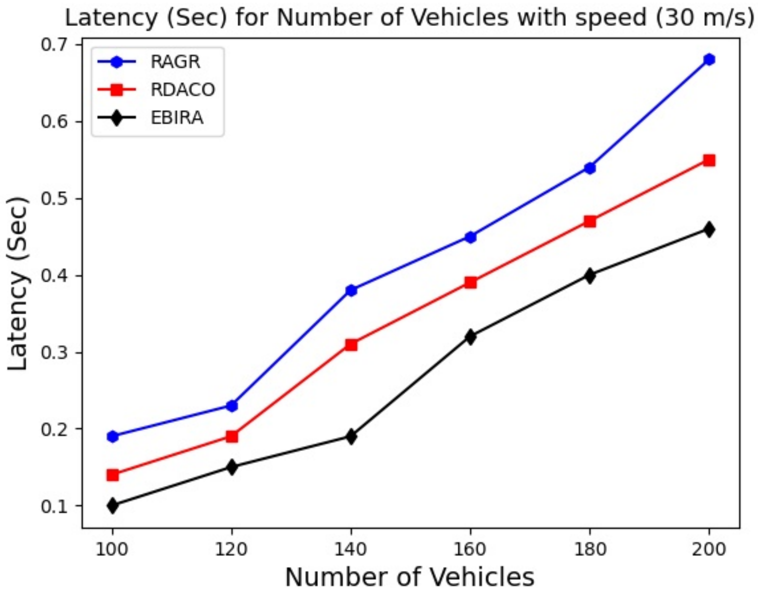

Figure 7 Latency based on the number of vehicles and speed (30 m/s).

RADCO's latency is low compared to RAGR. In RADCO, weightage for routes calculated based on delay, hop count, and stability. The route in RADCO is less delayed. Similarly in EBIRA, weightage (pheromone count) to paths is calculated based on $rssm_k$, distance, hop count, and evaporation rate. The high weightage paths are short in length and contain the least hops for routing the packets. Packet routing using the shortest route reduces the travel time of packets and latency. **Figures 6** and **7** depict the latency response of the proposed algorithm against RADCO and RAGR.

RSS vs. Vehicle density with speed

In the proposed model, the node measures the *RSS* when it receives a packet from a neighbor. **Figure 8** shows that *RSS* increases as vehicle density increases at different speeds in the network.

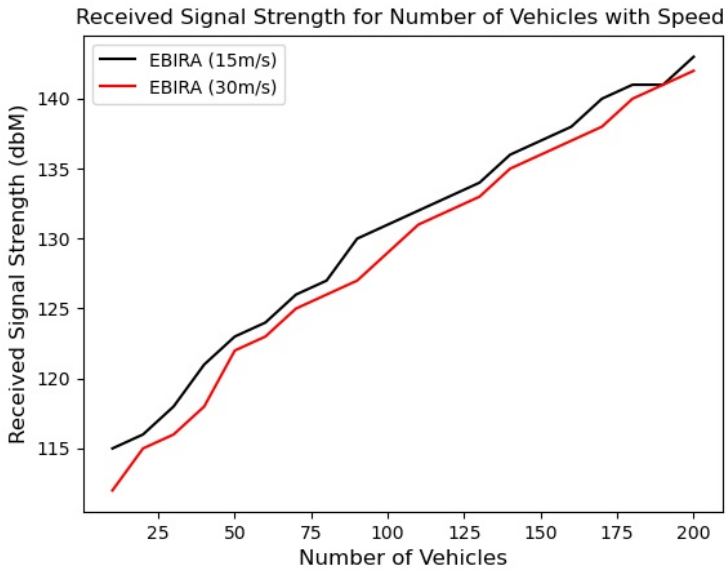

Figure 8 RSS vs. Vehicle density with speed (15 and 30 m/s)

The RSS increases as the vehicle density increases. As the distance between the two nodes increases, the *RSS* value decreases. Similarly, *RSS* increases as the distance between the 2 nodes decreases. The effect of vehicle density at different speeds affects the *RSS* levels of the nodes. Each node maintains an *RSS* record of neighboring nodes to find its neighbors within its broadcast range. The *RSS* of nodes is represented as dBm (decibel milliwatts).

Route discovery success ratio based on vehicle density at different speeds

Figure 9 shows EBIRA's route discovery success ratio over vehicle density at different speeds. The proposed EBIRA quickly determines the optimal route using EACO route selection strategy parameters. The vehicle intended to transmit the data using REQ-ANTs based on their neighbor list. REQ-ANTs quickly identify nearby neighbors to reach their destination without any delay. All successful REQ-ANTs are transformed into REP-ANTs at the destination and follow the route of REQ-ANTs to get the source. In EBIRA, the maximum number of REP-ANTs in all conditions reaches the source with optimal routes. The source can evaluate multiple REP-ANTs to find a stable long-life short-distance path. All REQ-ANTs and REP-ANTs determine multiple consistent paths between source and destination, which improves the path discovery success ratio.

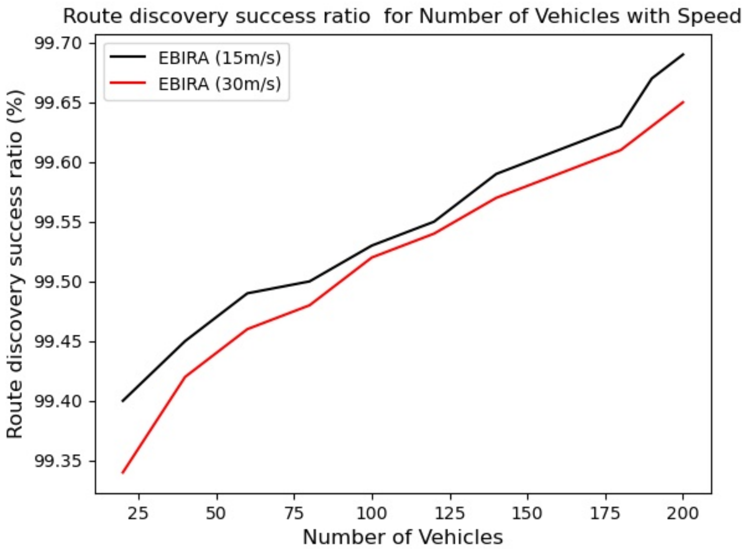

Figure 9 Route discovery success ratio over vehicle density with speed (15 and 30 m/s).

Conclusions

In this work, an enhanced bio-inspired routing algorithm (EBIRA) has been proposed to provide reliable communication to VANETs. The EACO determines a stable long-life short-distance route with the least hops over multiple computed routes based on pheromone count in the proposed model. EACO maintains stable pheromone count on short and high signal strength links based on the distance, received signal strength, hop count, and evaporation rate. In EBIRA, instead of building a route, the optimal route selection mechanism chooses the shortest path through minimal hops with high connectivity level links to improve route lifetime and reduce frequent link breaks between vehicles. The EBIRA route maintenance mechanism prevents the creation of new routes unnecessarily for broken routes. It reacts reactively to repair broken routes without delay and overhead. The simulation results prove that EBIRA outperforms RDACO and RAGR in terms of packet delivery ratio, throughput, and latency. The EBIRA has a better route discovery success ratio for different densities at different speeds without delay. For different vehicle density levels, EBIRA can quickly find multiple routes. An increase in vehicle density at different speeds improves the received signal strength and does not reduce EBIRA performance.

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