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Evaluation of efficient vehicular ad hoc networks based on a maximum distance routing algorithm

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Abstract

Traffic management at road intersections is a complex requirement that has been an important topic of research and discussion. Solutions have been primarily focused on using vehicular ad hoc networks (VANETs). Key issues in VANETs are high mobility, restriction of road setup, frequent topology variations, failed network links, and timely communication of data, which make the routing of packets to a particular destination problematic. To address these issues, a new dependable routing algorithm is proposed, which utilizes a wireless communication system between vehicles in urban vehicular networks. This routing is position-based, known as the maximum distance on-demand routing algorithm (MDORA). It aims to find an optimal route on a hop-by-hop basis based on the maximum distance toward the destination from the sender and sufficient communication lifetime, which guarantee the completion of the data transmission process. Moreover, communication overhead is minimized by finding the next hop and forwarding the packet directly to it without the need to discover the whole route first. A comparison is performed between MDORA and ad hoc on-demand distance vector (AODV) protocol in terms of throughput, packet delivery ratio, delay, and communication overhead. The outcome of the proposed algorithm is better than that of AODV.

Keywords: Traffic management, VANETs, Mobility, Routing, Communication overhead

1 Introduction

With the evolution of the Internet of things (IoTs), the vehicular ad hoc network (VANET) has been considered a crucial topic of research in the area of intelligent transportation systems (ITSs) [1]. ITSs inform drivers about unfavorable and dangerous road conditions such as weather situation, accidents, work zones, and emergencies (e.g., bushfire, flood) to improve road safety and traffic management and to provide value-added services while on the road [2, 3]. Proper information delivery needs an appropriate routing mechanism. The routing needs to route precise and updated information about traffic mobility (e.g., number of vehicles on the road and their directions and velocities). The collection and provision of this information can be done through VANETs by using two kinds of communication technologies, namely vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) [4, 5]. By delivering this information timely, better decisions can be made by drivers and accidents can be avoided.

However, traditional wireless technologies cannot be directly applied to VANETs because of several inherent features like high mobility, restriction of road setup, frequent topology variations, enough energy storage, failed network links, and timely data communication, which pose a major challenge in the routing of information [6–10]. To fulfill all the aforementioned communication requirements, an efficient routing protocol is required for conducting productive inter-vehicular communication.

For decades, several routing protocols have been proposed for vehicular networks [11–13]. The design of these protocols mainly focuses on the optimal route (shortest) with minimum hop count. For V2V, outstanding performance results have been exhibited by position-based routing as the routes between the source and the destination do not need to be established and saved, which satisfies the

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condition of dynamic changes in VANETs [14, 15]. Furthermore, in comparison to other types of routing protocols, such protocols support scalable networks with reduced control message overhead [16]. Finally, they are simple because they apply the global positioning system (GPS) technology to determine the exact positions of a vehicle with respect to its longitude and latitude [17]. Therefore, a position-based routing protocol is considered the best choice for this work. Some protocols [18, 19] face problems with conflicting nodes. Distance is the main factor that plays an important role in making routing decisions in VANETs and finding the next hop node for forwarding packets. However, it is not enough for efficient routing and needs to add other factors such as velocity, position, direction, and density [14]. The combination of these factors still remains a challenging problem. This paper addresses these challenges by combining velocity and position factors into one new factor called communication lifetime. As a result, distance, direction, and communication lifetime factors are considered for the routing decision. Therefore, a novel position routing for finding an optimal route is considered in this paper.

In this work, a novel routing algorithm called as maximum distance on-demand routing algorithm (MDORA) is proposed by analyzing the existing problems. This algorithm comprises two phases, the ad hoc discovery phase and the route establishment and data transmission phase. This paper presents the following important contributions.

1. Distance ($Dist_f$) and communication lifetime (CLT_f) factors have been defined to determine the optimal next hop node. $Dist_f$ is computed to select the closest node toward the destination, and CLT_f represents the duration for which a node remains in the radio range of the forwarder.
2. The performance evaluation of the proposed MDORA is compared against AODV by using a real map (Baghdad city) as a case study to validate and authenticate the simulation results. The simulation signifies that MDORA has a higher throughput and packet delivery ratio and lower delivery delay and communication overhead than AODV.

The paper is organized as follows: Section 2 presents the literature review of VANET routing. Section 3 discusses the proposed algorithm (MDORA). Section 4 presents the scenario implementation and numerical analysis of the results. Section 5 concludes the ideas proposed throughout the paper.

2 Related woks

VANET is a secondary class of mobile ad hoc network (MANET) that uses the capabilities of new generation wireless networks for vehicles [20–22]. Routing protocols have been widely discussed in the literature regarding MANET, which were originally produced with a fixed or minimal node speed and a random topology, such as the random waypoint model. However, vehicles generally adhere to predicable routes and on road lanes, which allows them to travel at extremely high speeds. Accordingly, routing protocols of MANETs are not suitable for VANETs. Therefore, VANETs require new types of routing protocols. VANET routing protocols are classified into topology-based, position-based, cluster-based, geocast-based, multicast-based, and broadcast-based routing protocols. This section focuses on two types of routing, topology-based routing protocols and position-based routing protocols.

2.1 Topology-based routing protocols

Routing tables, which contain link information, are used by this class of routing protocols. Depending on this information, the decision of transmitting information from the source node to the destination node is made. Proactive [11], reactive [12, 23], and hybrid [24] are the three kinds of topology-based routing protocols.

Optimized link state routing (OLSR) is proposed in [11]. OLSR is a known MANET routing protocol of unicast nature, which has been efficiently altered for VANETs. The concept of multipoint relays (MPRs) is used in OLSR. MPRs are a pair of nodes chosen by the network nodes for retransmitting their packets. The network is in a fully connected state with routes available between any two network nodes due to the appointment of MPRs. However, this advantage comes at the cost of high route maintenance overhead.

Dynamic source routing (DSR) is proposed in [12], which is a widely used routing protocol. It is an on-demand routing protocol, which comprises two important phases: (1) route discovery and (2) route maintenance. Instead of relying on routing tables of intermediate nodes, source routing is used in DSR. Hence, the length of the routing path determines the routing overhead. However, the DSR protocol is relatively inefficient because of the absence of the route maintenance process to repair failed links. Moreover, DSR operates effectively in static or low-mobility environments. Vehicles with high mobility lead to a deteriorating performance of this routing model.

Ad hoc on-demand distance vector (AODV) is proposed in [23]. In AODV, Hello beacons are generated by the source node to determine its neighbors. Once the neighbors are detected, a route request (RREQ) packet is broadcasted by the source node, which in turn is broadcasted by its neighbors. The process continues until RREQ reaches the destination node. Once the RREQ packet is received by the node, a source address is registered in its routing table. When the destination receives the RREQ message, it sends a route reply (RREP) packet to the source, which travels backward through the same learned path as that of RREQ. In this protocol, excessive bandwidth is consumed due to generation of periodic Hello messages. Moreover, the flooding of route discovery requests incurs high overhead if multiple RREP packets are received in response to a single RREQ. Furthermore, the AODV protocol introduces high latency in the route creation process.

Hybrid ad hoc routing protocol (HARP) is proposed in [24]. HARP categorizes a network into non-overlapping zones and tends to create a stable route from the source to the destination along with delay improvement. Route discovery is performed between the zones of the network for run-over confinement. Constancy features are used for selection of the best routes. Depending on the location of the destination, two-level routing is performed in HARP: intra-zone and inter-zone. Proactive protocols are employed in intra-zone routing whereas reactive protocols are employed in inter-zone routing.

2.2 Position-based routing protocols

In position-based routing protocols, the location of all nodes and their neighboring nodes are determined through positioning devices such as GPS. Such protocols do not need to maintain routing tables or share information related to valid network links with their neighboring nodes. Routing decisions are made utilizing the information obtained from a GPS device. Better performance results are exhibited by these routing protocols as the route maintenance phase between the source and the destination is eliminated. The three categories of position-based routing protocols include non-delay-tolerant network (non-DTN) routing protocols [13, 18, 25, 26], delay-tolerant network (DTN) routing protocols [27], and hybrid routing protocols [28].

Greedy perimeter stateless routing (GPSR) is presented in [13], which is a position-based routing protocol and designed to handle mobile environments. Usually, desirable performance results can be obtained by GPSR in environments where nodes are uniformly distributed, such as highways. There are two modes involved in the routing process: (1) greedy mode and (2) perimeter mode. The requirements of urban environments are not fulfilled by GPSR. Firstly, failure of greedy forwarding is observed in case of obstacles as direct communication between nodes is not possible. Secondly, if the greedy forwarding technique does not work, GPSR toggles to face routing (recovery mode) as no neighbor that is closer to the destination is found by the node other than itself during greedy forwarding. An extended route is picked to reach the destination by the face routing to which packet losses, delay time, and hop count are increased.

Geographic source routing (GSR) is proposed in [25]. Designed for urban environments, the GSR protocol integrates topological information with position-based routing. One downside of GSR is that it is not suitable for sparse networks with insufficient forwarding nodes. GSR is unsuitable for long-haul routes because excessive control overheads are required to transmit data between the source and the destination. Packets are discarded when a local maximum occurs at a road segment, thereby preventing the driver from progressing to the next available access point.

Predictive directional greedy routing (PDGR) is proposed in [26]. The weighted score in PDGR is calculated from two approaches: position-first forwarding and direction-first forwarding. A prediction-based next hop selection is done, which is unreliable in certain circumstances. It is not guaranteed that the edge node of the transmission range will receive packets in case when it can serve as a next hop node due to highly dynamic traffic scenarios. Hence, lower packet delivery rates, higher network delays, and increased routing overhead are observed.

Border node-based most forward within radius (B-MFR) is proposed in [18]. It works on the mechanism of minimizing the hop count between the source and the destination by selecting a border node present in the communication range of the sender. The nodes are categorized into the following: interior, border, and outer nodes. The selection of the border node is done as the forwarding node because it is the most distant neighboring node of the source and the closest node to the destination. All the border nodes are projected on the straight line connecting the source and the destination, and the farthermost is selected by B-MFR. However, this selection is an extensive process.

Vehicle-assisted data delivery (VADD) is proposed in [27]. VADD is based on the carry-and-forward technique and is used to improve routing in disconnected vehicular networks. The decision regarding the next forwarding route is made at the intersection with preference to the one offering minimal packet delivery delay. The intersection is divided into branches one of which serves as the chosen path. Three packet modes are swapped to select the packet forwarding path: (1) intersection, (2) straight way, and (3) destination. If failed network links are observed during the network operation, VADD can result in selecting an incorrect path and leads to poor performance. Also, vehicle density is variable whereas VADD calculates packet forwarding delay using data based on certain stats. Hence, if up-to-date data concerning vehicular density is not available to the node that needs to forward data, an incorrect path may be selected.

GeoDTN+Nav is proposed in [28]. It is a combination of non-DTN and DTN routing protocols that includes the greedy mode, the perimeter mode, and the DTN mode. The switching from the non-DTN mode to the DTN mode is done by predicting network connectivity based on the hop count of the packet, data delivery quality of the neighbor node, and direction of the neighbor node with respect to destination. GeoDTN+Nav is a hybrid protocol, which not only provides protection of private data but also helps in taking the best-effort routing decision.

This paper presents the MDORA algorithm to address the aforementioned problems inherent in VANET routing protocols. The novelty of this work lies in its unique design based on distance, direction, and communication lifetime to select the optimal next hop node in the optimal forwarding route. The proposed routing mechanism is based on hop by hop, which decreases control overhead by calculating the route with the least number of possible hops over a maximal distance.

3 MDORA

3.1 Assumption

For the system model, a vehicular network in an urban environment is considered. It estimates a sequence of intersections from the source vehicle to the destination vehicle. Between intersections, there are segments having two lanes in which vehicles are moving in the opposite direction. In addition, we consider that each vehicle in the network easily obtains its accurate position as well as its velocity and direction with the help of real-time GPS information. Moreover, in order to make a routing decision, the source vehicle needs to be aware of the destination's real-time geographical location. The location service such as city-scale wireless sensor networks makes it possible. The routing algorithm assumes that during packet transmission every vehicle follows a constant movement pattern. Also, position estimation is assumed to be accurate and error free. The error consideration in this phase is left for future study.

3.2 Description of MDORA

MDORA is a position-based routing protocol designed for VANETs that generates on-demand routes between vehicles. In this algorithm, real-time traffic data is used to form an ad hoc region connectivity graph between the source vehicle and its neighboring vehicles. The ad hoc region connectivity graph determines the distance between neighboring vehicles. Depending on the longest duration of communication lifetime, intra-vehicular distance, and destination vehicles' position data, a suitable path is chosen for data routing. Figure 1 shows the flowchart of MDORA, which comprises two phases: ad hoc discovery phase and route establishment and data transmission phase.

3.2.1 Ad hoc region discovery phase

This initialization phase is started by the source vehicle, by broadcasting the request message (Hello_msg) to all neighboring vehicles within its communication range (Rc). The Hello_msg message contains information fields as shown in Fig. 2. Whenever the source vehicle issues a new Hello_msg, the message identifier (M_ID) is incremented by one. Thus, the source identifier (S_ID) and message identifier (M_ID) together uniquely identify this Hello_msg. This unique identifier not only helps in uniquely identifying a message by the neighbor vehicle but also determines whether the message is new or a reply has already been sent to this message.

At that very instant, a timer (T) is started by the source vehicle, which continues for a specific time period. During this time, if any neighbor vehicle does not generate a response, then broadcasting of Hello_msg is repeated. Each vehicle, upon receiving the Hello_msg, verifies if its direction is identical to the direction stored in the Hello_msg, as shown in algorithm 1—line 7. If the direction is identical, then the neighbor vehicle responses by sending a unicast response message (Response_msg) to the source vehicle with information fields as shown in Fig. 3. Otherwise, if that condition is false, this means that the vehicle is moving in a different direction, and it discards the received Hello_msg (algorithm 1—line 10). Figure 4 shows an example of the ad hoc region discovery phase.

MDORA helps in taking advantage of the up-to-date position and direction information of the vehicle and the communication lifetime so that a next hop vehicle can be chosen for forwarding packets.

The procedure of considering distance factor ($Dist_f$) in finding the next hop neighbor vehicle is presented in Fig. 5. Line segment *SD* joining the source and the destination is drawn to project vehicles n_1 and n_2. The shortest distance between the source and destination vehicles is denoted by *DC* whereas *d* and d′ denote the distances from intermediate vehicles (n_1 and n_2) to the source and the destination, respectively. Dn_1 and Dn_2 are the distances that measure the progress of vehicles n_1 and n_2 from the source vehicle toward the destination vehicle, and this distance can be calculated from the formula below, which is defined as follows:

$$\mathrm{Dist_f} = \frac{\mathrm{Dist}^2(S,D) + \mathrm{Dist}^2(S,n) - \mathrm{Dist}^2(n,D)}{2 \times \mathrm{Dist}^2(S,D)} \qquad (1)$$

where

$$\mathrm{Dist}\ (S,D) = \sqrt{(x_{Dx}-x_{Sx})^2 + \left(y_{Dy}-y_{Sy}\right)^2}$$

$$\mathrm{Dist}\ (S,n) = \sqrt{(x_{nx}-x_{Sx})^2 + \left(y_{ny}-y_{Sy}\right)^2}$$

$$\mathrm{Dist}\ (n,D) = \sqrt{(x_{Dx}-x_{nx})^2 + \left(y_{Dy}-y_{ny}\right)^2}$$

Hence, the vehicle with the maximum distance ($Dist_f$) toward the destination will be selected as the next hop. Figure 5 shows that according to the distance factor selection, vehicle n_2 should be preferred to vehicle n_1.

The communication lifetime factor (CLT_f) defines the duration for which a vehicle remains in the radio range of the forwarder. Thus, while selecting the next hop, based on the communication lifetime factor, a vehicle predicts the communication link expiration time with its neighbors. It is assumed that two vehicles, *i* and *j*, are within each other's transmission range denoted by *r*, coordinates (x_i, y_i) and (x_j, y_j). Also, let v_i and v_j be the velocities of vehicles i and j, respectively. CLT_f between two vehicles will be computed as follows:

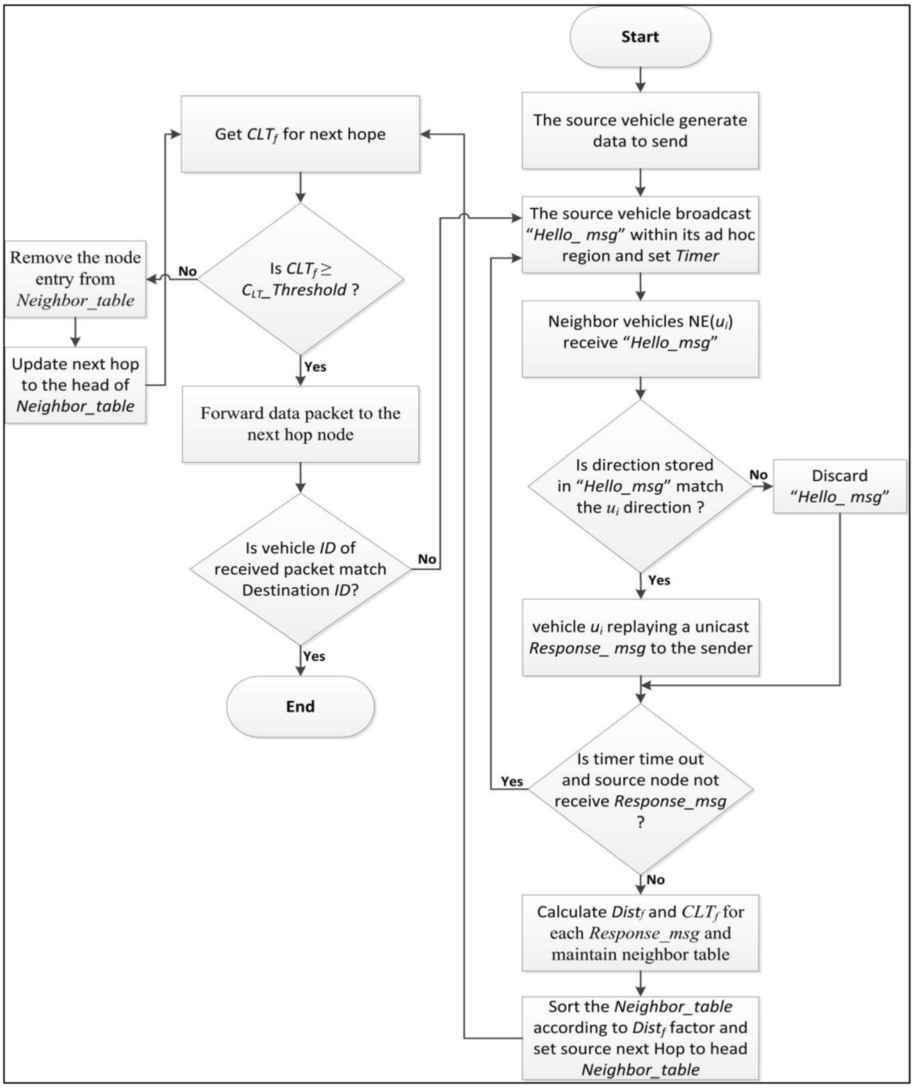

Fig. 1 Flowchart of MDORA

$$\mathrm{CLT_f} = \frac{-(ab+ac)+\sqrt{(a^2)r^2-(ac-ab)^2}}{a^2} \qquad (2)$$

where $a = v_i - v_j$, $b = x_i - x_j$, and $c = y_i - y_j$

Note that when $v_i = v_j$, the communication lifetime CLT_f becomes infinity.

After computing $Dist_f$ and CLT_f factors for each neighbor vehicle, the source vehicle initiates a neighbor table (Neighbor_table) comprising of Neig_ID, $Dist_f$, and CLT_f. Then, the source vehicle sorts the Neighbor_table according to the $Dist_f$ factor, which is the highest $Dist_f$, first (algorithm 1—lines 15 to 18).

Finally, in this phase, the source vehicle updates the routing table by setting the next hop to the ID of the neighbor vehicle, which is the head of Neighbor_table (algorithm 1—line 18). Algorithm 1 shows the detail of the ad hoc region discovery phase in MDORA.

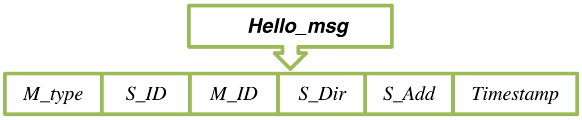

Fig. 2 Hello message information

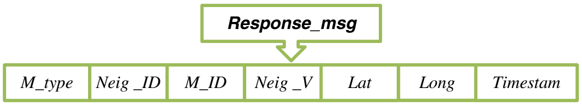

Fig. 3 Response message information

Algorithm 1 Ad hoc region discovery phase

```
Input: The information of sender vehicle
Output: The next hop ID
Notation:
M_type: Message type (Hello, Response, Data)
S_ID: Source vehicle identifier
M_ID: Message unique identifier
S_Add: Source address
S_Dir: Source direction
Timestamp: Request or response time
T: Timer
$R_c$: Communication range
NE: Neighbor vehicles
Neig_ID: Neighbor vehicle identifier
Neig_V: Neighbor vehicle velocity
Lat: Latitude
Long: Longitude
N_Hop: Next hop

1.  Begin Algorithm 1
2.  The source vehicle $v$ generate data to send;
3.  The vehicle $v$ broadcasts the initialization message "Hello_ msg" with fields:
    M_type, S_ID, M_ID, S_Dir, S_Add, Timestamp;
4.  Source vehicle $v$ sets $T$;
5.  "NE" is the set of vehicles in a network that receive Hello_msg such that $u \in NE$; // NE all vehicles within the communication range $R_c$ of a source vehicle
6.  Foreach $u \in NE$
7.      If Dir($u_i$)== Dir(HELLO_msg) then
8.          vehicle $u_i$ replaying a unicast Response_ msg to the sender (vehicle $v$) with
            fields: M_type, Neig_ID, M_ID, Neig_V, Lat, Long, Timestamp;
9.      Else
10.         vehicle is discard Hello_ msg;
11. End For.
12. If $T$ time out and vehicle $v$ not receive any Response_ msg then
13.     Go to 3;
14. Else
15.     Vehicle $v$ compute the ($Dist_f$ and $CLT_f$) for each Response_msg;
16.     Vehicle $v$ maintain the on demand Neighbor_table with insert (Neig_ID,
        $Dist_f$, $CLT_f$);
17.     Sort the Neighbor_table according to $Dist_f$ (highest value first);
18.     Vehicle $v$ update the Routing_table by sets: N_Hop($v$) = Neig_ID (head of
        Neighbor_table);
19. End Algorithm 1.
```

3.2.2 Route establishment and data transmission phase

In this phase, MDORA starts the process with the current forwarding vehicle (*c*) to establish the routing path. This phase depends on the link expiration time between the two vehicles denoted by CLT_f and computed as in Eq. (2). From Neighbor_table, MDORA checks the CLT_f of the next hop vehicle to be sure that this vehicle remains in the communication range of the forwarder. Hence, one metric is defined as the communication lifetime threshold (C_{LT}_Threshold), which is the minimum time needed for the data transmission process. It is used to evaluate the communication lifetime of the next hop vehicle. If CLT_f of the next hop vehicle is greater or equal to C_{LT}_Threshold, then the current vehicle starts forwarding the packet to the next hop vehicle, as shown in algorithm 2—lines 5 and 6. Otherwise, if that condition is false, then the vehicle entry is removed from the Neighbor_table, a new head of the Neighbor_table is set as the next hop vehicle, and the

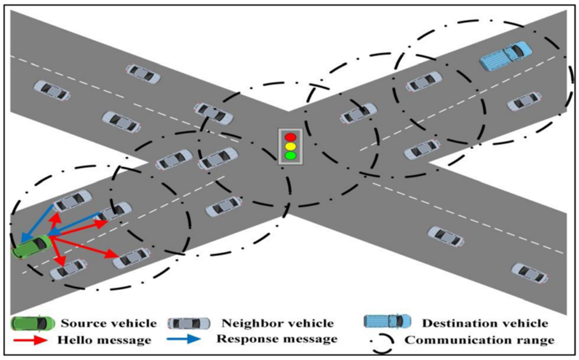

Fig. 4 Ad hoc region discovery phase

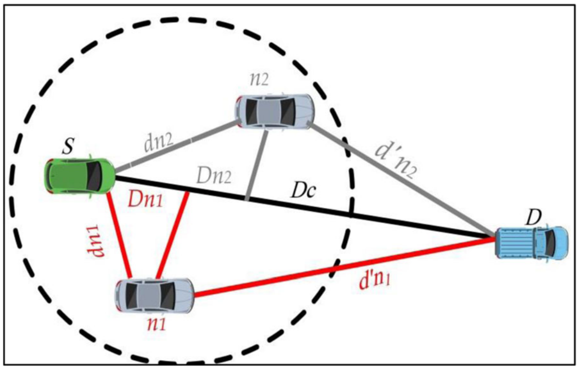

Fig. 5 Impact of distance factor in finding the next hop forwarding vehicle

verification condition of CLT_f is repeated. Finally, the algorithm compares the destination vehicle identifier (D_ID) with Neig_ID of the next hop vehicle. If the identifiers are identical, then the algorithm is terminated. Otherwise, if the identifiers are not identical, then the next hop vehicle broadcasts Hello_msg and starts the ad hoc region discovery phase. This procedure will continue until the destination vehicle is reached as shown in Fig. 6. Algorithm 2 presents the detail of the route establishment and data transmission phase in MDORA.

4 Performance evaluations

In this section, we first present the scenario implementation and then introduce the result analysis.

4.1 Scenario implementation

A particular region in Baghdad city is selected to perform a case study as shown in Fig. 7. Google Maps is used to extract an intersection image. MATLAB is used to design this scenario. Realistic scenarios can be achieved in simulations with the assistance of mobility models, which

Algorithm 2 Route establishment and data transmission phase

Input: The ID of next hop vehicle and destination vehicle
Output: Forward the data packet toward destination vehicle
Notation:
c: The current forwarding vehicle
C_{LT}_Threshold: The communication lifetime threshold
D_ID: Destination vehicle identifier

```
1.  Begin Algorithm 2
2.  The current forwarding vehicle $c$ starts to establish routing path;
3.  Repeat
4.      Get the $CLT_f$ ($u_i$) where $u_i$ = N_Hop($c$);
5.      If $CLT_f$ ($u_i$) ≥ $C_{LT}$_Threshold then
6.          Forward packet to ($u_i$);
7.          If (D_ID= =Neig_ID($u_i$)) then
8.              Go to 16;
9.          Else
10.             Neighbor vehicle $u_i$ broadcasts the Hello_msg and run the command line
                4 until the line 19 of Algorithm 1;
11.     Else
12.         Remove the neighbor vehicle entry from Neighbor_table;
13.         Update N_Hop($c$) = Neig_ID (new head of Neighbor_table);
14.         Go to 4;
15. Until finds the destination vehicle
16. End Algorithm 2.
```

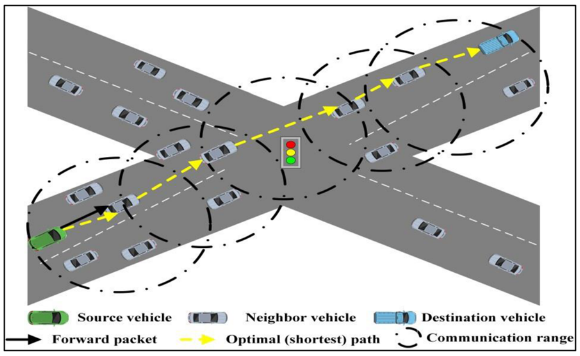

Fig. 6 Route establishment and data transmission phase

enable vehicles to change direction, accelerate, and decelerate in the simulation environment. Two well-known mobility models are used for this part of the study. First, the car following model (CFM) is the standardized and widely used driver model [29]. Continuous functions of time, speed, position, and acceleration are characterized by this driver model. One of the advantages of using this model is its simple design approach. Second, the cellular automata model (CA) is a discrete time and space model [29]. CA models driver behavior in various environmental scenarios with reduced computational complexity.

4.2 Result analysis

In this section, we evaluate the performance of the proposed MDORA with AODV. The following figures illustrate the comparison of the performances of the proposed MDORA and AODV in terms of throughput, packet delivery ratio, delay, and communication overhead. Simulations have been performed at different hours within a day. In the simulation, a small packet size of 512 bytes and a low packet generation rate of 5 packets/s are used, to model a safety event notification, rather than an infotainment application, which are similar to the parameters used in [30]. Each algorithm is simulated under two mobility models, namely CFM and CA. Table 1 lists the simulation parameters used in this study.

Figure 8 illustrates the throughput of the network measured in kilobits per second. Throughput is the total amount of packets per second delivered successfully to the destination during the entire course of the simulation. We compare the throughput of AODV with MDORA under different network densities. The results in Fig. 8 show that the throughput of MDORA is higher than that of AODV at low and high densities for both of the two mobility models. The throughput is influenced by the vehicle density and the average distance between vehicles that determine whether vehicles can properly communicate. Furthermore, the packet success probability for a particular link is highly affected by link quality. In MDORA, the link with the highest probability of connectivity is selected to forward packets, which results in a higher link quality per hop and higher packet delivery rates than those for AODV. Therefore, the throughput of MDORA is the highest. The peak time between 6:00 a.m.–8:00 a.m. and 2:00 p.m.–4:00 p.m. has a high number of vehicles, which causes an increase in throughput. This behavior results from the successive

Table 1 Simulation parameters

Parameter	Value
Simulation area	3 km * 5 km
Number of lanes	2 Bidirectional
Number of vehicles	1000
Velocity	(40–80) km/h
Communication radius	100 m
MAC protocol	IEEE 802.11p
Peak time	(6:00–8:00) a.m. and (2:00–4:00) p.m.
Normal time	08:00 a.m.–02:00 p.m.
Transmission rate	5 packet/s
Transmit power	23 dBm
Path loss model	Log-distance
Control message size	64 bytes
Packet size	512 bytes
Simulation time	300 s

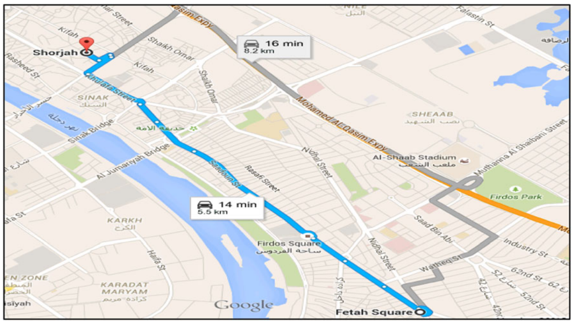

Fig. 7 Route map of Baghdad city

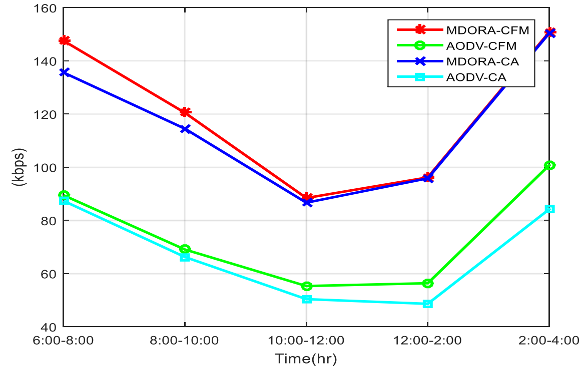

Fig. 8 Throughput for different network densities within a day

movement of the packet toward the destination, wherein numerous vehicles are present to provide connectivity. Thus, when the number of vehicles is increased, the number of packets delivered to the destination also increases. Such increase will result in a higher throughput because throughput is the total amount of packets per second delivered successfully to the destination. By contrast, the time between 08:00 a.m. and 02:00 p.m. is considered normal time, which has less number of vehicles. Hence, less delivered packets cause a rapid decrease in throughput. Compared with all four routing approaches, MDORA-CFM has a higher throughput, which is approximately 85 and 145 kbps in low and high densities, respectively.

Figure 9 illustrates the packet delivery ratio measured in percentages. Packet delivery ratio is defined as the ratio of all successfully received data packets at the destination vehicle to the total data packets generated by the source vehicle. The figure shows that the packet delivery ratio of MDORA is higher than that of AODV at high and low densities in the two mobility models. This finding is explained by the highest connection probability provided by the routes selected by MDORA. Hence, a high probability of selecting the next hop on the chosen path exists. Therefore, MDORA is effective and less prone to failure in finding a path toward the destination, which results in a higher number of packets to reach the destination. By contrast, the AODV protocol still incurs a high data loss rate when routes are disconnected or when collisions occur. Moreover, AODV is unable to maintain a communication link in high-speed moving vehicles. Therefore, the packet delivery rate of ADOV is less than that of MDORA. From Fig. 9, we observe that the peak time between 6:00 a.m.–8:00 a.m. and 2:00 p.m.–4:00 p.m. has a high delivery ratio. This finding is attributed to the higher number of packets delivered to the destination. The packet moves continuously toward the destination and maintains connectivity because of the presence of numerous vehicles surrounding the destination. By contrast, the time between 08:00 a.m. and 02:00 p.m. is considered normal time, during which a lower number of packets are delivered because of the less number of vehicles, which causes the decrease in the delivery ratio. Compared with all four routing approaches, MDORA-CFM has a higher packet delivery ratio, which reaches 0.59–0.67 at different densities during the day.

Figure 10 illustrates the delay of the network measured in milliseconds. Delay is defined as the difference between the time a packet is received at the destination and the time the packet is sent by the source. From the figure, the delay of MDORA is minimum than that of AODV at different densities for both mobility models. This finding is attributed to MDORA being a maximum distance-based routing algorithm. The packet reaches the destination using fewer hops, thereby minimizing delay. By contrast, congestion and delay in AODV increase because of flooding in the route discovery, which congests the network while requiring constant updates. As shown in Fig. 10, the peak time between 6:00 a.m.–8:00 a.m. and 2:00 p.m.–4:00 p.m. exhibits a lower delay. This finding is attributed to the fact that the number of hops is reduced during this period, which causes the packets to reach the destination faster. Therefore, delay is decreased when delivery is fast. By contrast, the time between 08:00 a.m. and 02:00 p.m. is considered normal time, and delay is increased. This finding is attributed to the increase in the number of hops during this period, which slows the process of packet delivery to the destination. Therefore, delay is increased when delivery is slow. Compared with all four routing approaches, MDORA-CFM exhibits lower delay, which is approximately 50–250 ms at different densities during the day.

Figure 11 illustrates the communication overhead of the network at different densities during the day measured in bytes. Overhead is defined as the number of control messages sent by the routing protocols to construct and maintain their routes. The figure shows that the overhead of AODV is higher than that of MDORA at high and low

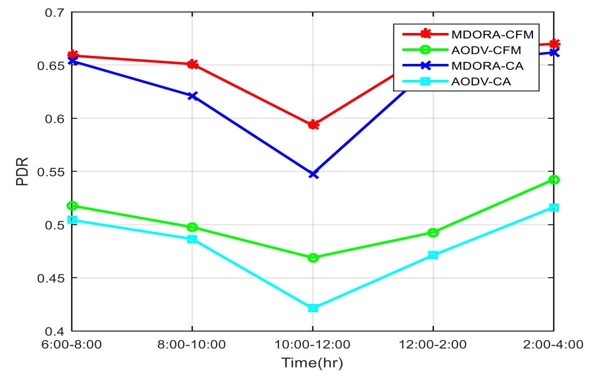

Fig. 9 Packet delivery ratio for different network densities within a day

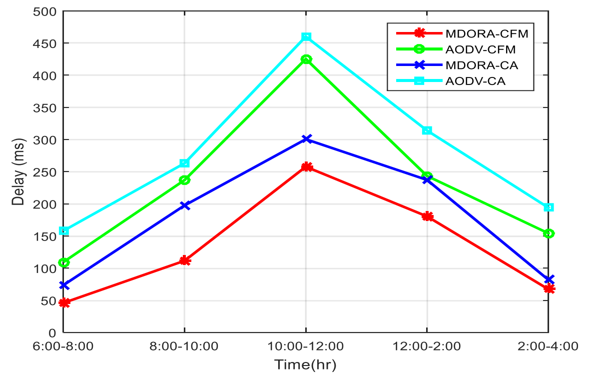

Fig. 10 Delay for different network densities within a day

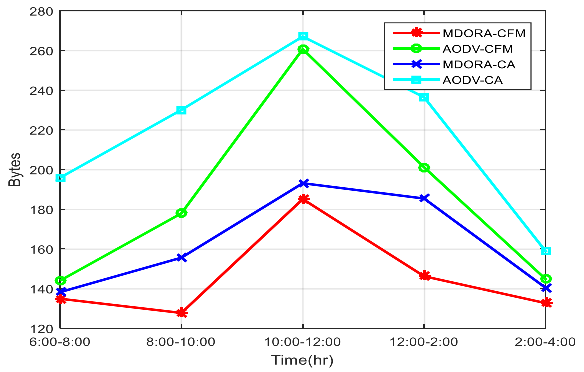

Fig. 11 Communication overhead for different network densities within a day

densities in the two mobility models. The flooding of route discovery requests in AODV requires more control overhead than that in MDORA; therefore, MDORA has less overhead. As shown in Fig. 11, the peak time between 6:00 a.m.–8:00 a.m. and 2:00 p.m.–4:00 p.m. has lower overhead. This finding is attributed to the less number of hops during this period, which indicates that the packet is delivered to the destination with the minimum number of control messages (Hello and Response messages). Therefore, overhead is decreased although the number of vehicles is increased. By contrast, the time between 08:00 a.m. and 02:00 p.m. is considered normal time, and overhead is increased. This finding is attributed to the higher number of hops during this period, which indicates that the packets are delivered to the destination with more control messages (Hello and Response messages). Therefore, the overhead is increased although the number of vehicles is decreased. Compared with the four routing approaches, MDORA-CFM has a lower overhead, which is approximately 130–190 bytes at different densities during the entire day.

Lastly, on the basis of the aforementioned figures, the results show that MDORA is more reliable to use in VANET than AODV. Moreover, the CFM model provides better results than the CA model for both AODV and MDORA.

5 Conclusions

In this paper, the proposed MDORA provides an optimal route for end-to-end data delivery in urban VANET environments. The novelty of this work lies in its unique design based on distance, direction, and communication lifetime to select the optimal next hop vehicle in the optimal forwarding route. MDORA consists of two phases, ad hoc discovery phase and route establishment and data transmission phase. The proposed routing mechanism is based on hop by hop, which minimizes control overhead by calculating the route with the least number of possible hops over a maximal distance. A particular region in Baghdad city is selected to perform a case study of this work. Simulations have been performed at different hours during the day. The simulated results have shown that MDORA proves to be superior to AODV in terms of throughput, packet delivery ratio, delay, and communication overhead.

Abbreviations

AODV-CA: Ad hoc on-demand distance vector based on cellular automata model; AODV-CFM: Ad hoc on-demand distance vector based on car following model; MDORA-CA: Maximum distance on-demand routing algorithm based on cellular automata model; MDORA-CFM: Maximum distance on-demand routing algorithm based on car following model

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Authors' contributions

YRBA-M contributed to the conception and design and experiments and analyzed the data. NFA carried out the experiments and analyzed the data. MI conceived and designed the experiments and drafted the manuscript. SMA-Q drafted and critically reviewed the manuscript. OAM analyzed the data and drafted the manuscript. SK carried out the experiments, analyzed the data, and critically reviewed the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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