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# An Opportunistic Routing for Data Forwarding Based on Vehicle Mobility Association in Vehicular Ad Hoc Networks

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**Abstract:** Vehicular ad hoc networks (VANETs) have emerged as a new powerful technology for data transmission between vehicles. Efficient data transmission accompanied with low data delay plays an important role in selecting the ideal data forwarding path in VANETs. This paper proposes a new opportunity routing protocol for data forwarding based on vehicle mobility association (OVMA). With assistance from the vehicle mobility association, data can be forwarded without passing through many extra intermediate nodes. Besides, each vehicle carries the only replica information to record its associated vehicle information, so the routing decision can adapt to the vehicle densities. Simulation results show that the OVMA protocol can extend the network lifetime, improve the performance of data delivery ratio, and reduce the data delay and routing overhead when compared to the other well-known routing protocols.

**Keywords:** VANETs; opportunistic routing; vehicle association; data forwarding

## 1. Introduction

In recent years, vehicular ad hoc networks (VANETs) have seen an increased interest due to their wide combination with wireless communication technologies. VANETs are a particular type of mobile ad hoc network (MANET) in which vehicles act as nodes with the aim of achieving communication between vehicles.

Currently, due to the rapid development of wireless network technology [1], vehicle networks are developing rapidly. With the mobile Internet exchange speed at a moderate stage, vehicle technology will be based on the use of smart phones and a vehicle network model. The vehicle network will use smart phones as a storage intermediary, vehicles' built-in entertainment systems will be used to play music from smart phone storage, and smart phones will be used for GPS navigation, to display smart phone mail, SMS, and current news. As a storage intermediary, smart phone storage software and data information can be synchronized with computers and cloud servers. The vehicle network model based on cloud computing is proposed on the basis of the requirement that the information transmission speed of the mobile Internet can satisfy the real-time information download. The vehicle system can play and display cloud server information through real-time download, and call on the network information resources. The vehicle information will synchronize the data to the cloud server and the personal computer information , and even store the information directly in the cloud server. At present, vehicle network communication technology has reached a certain point. Most of the vehicle deployment becomes increasingly possible and feasible. On the one hand, the deployment is waiting for vehicle designers to embed the dedicated short range communications (DSRC)/wireless access in a vehicular environment (WAVE) inside the vehicle. On the other hand, cellular system communication technologies such as General Packet Radio Service (GPRS), Enhanced Data Rate for GSM Evolution (EDGE), 3G, and Long Term Evolution (LTE) [2].

Alerting drivers about traffic and road conditions, and other related aspects are essential to safety [3]. To accomplish this, timely and accurate information delivery is crucial. The typical problems of VANETs are shown in Figure 1. Emergencies can be prevented by exploiting the instruments supplied by VANETs technologies—in other words, all information related to vehicle mobility, such as speed, the direction of vehicles' travel, vehicle density, etc., which are gathered by using Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) [4], and other communication technologies. That information helps to organize road traffic and prevent accidents. The three the most common vehicle communication technologies are V2V, V2I [4], and dedicated short range communications (DSRC). For Vehicle-to-Vehicle (V2V),a number of wireless transmission technologies can be realized in the physical layer. Examples include IEEE802.11 [5], 3G, WiMax [6], etc. IEEE802.11 is an appropriate technology to provide the wireless connection in VANETs due to its deployment cost, delivery data rate, and service fees [7]. However, due to the high mobility and the limited transmission range from the antenna, handoff is frequent in VANETs.

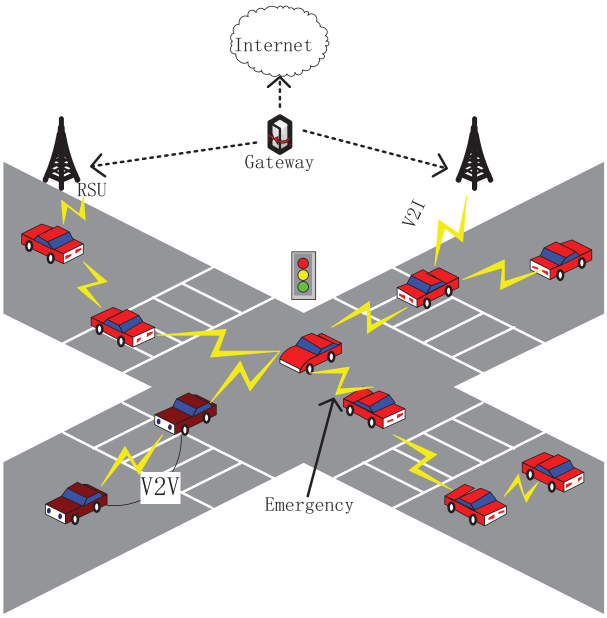


**Figure 1.** Generalized architecture in vehicular ad hoc networks (VANETs).

The main challenge of these kinds of vehicles for applications is in finding a way to maintain a persistent connection with the vehicle in order to deliver data from source to destination via wireless transmission or storage-carry-forward techniques. The design of effective data forward methods is crucial in the development of this technology. Accordingly, some research work has recently been conducted on this topic. Among the existing methods, some studies are concerned with selecting a candidate intersection to forward data regarding the density of vehicles off the road, using a method such as vehicle-assisted data delivery (VADD) [8]. However, not only the vehicle density but also the association degree of vehicles can affect the vehicles' connectivity.

This paper focuses on how to achieve fast data forwarding and transmission in the case of low latency and low routing overhead. In this study, the proposed algorithm: An Opportunistic Routing for Data Forwarding Based on Vehicle Mobility Association (OVMA) using the vehicle mobility association can find an optimal path to deliver data from the source vehicle to the destination vehicle, without having to pass through many unwanted intermediate vehicleswith a low degree of association.

OVMA calculates the probability of data transmission between nodes by comparing the association between nodes and chooses the path with the highest probability of data transmission as the optimal data propagation path. The association between nodes is measured by the information transmission efficiency of the whole network G and the information center degree of the corresponding edge from the node. The data transmission probability is built into the Hidden Markov Model(HMM) decision. It is designed as a two-phase algorithm, which ensures that the data delivery can adapt to the vehicle density.

The rest of paper is organized as follows. In Section 2, we introduce some different routing protocols in vehicular ad hoc networks; OVMA is shown in Section 3; a simulation experiment and results analysis are introduced in Section 4; finally, Section 5 concludes the paper.

## 2. Related Works

VANETs are an indispensable foundation of modern intelligent transportation. The special characteristics of VANETs such as high mobility, frequent network disconnections, frequent topology changes, uncertainty distribution of vehicles, and insufficient power supply differentiate them from MANETs. Thus, traditional MANET routing protocols are not suitable for VANETs, while routing continues to be one of the challenges in VANETs.

The Destination-Sequenced Distance-Vector Routing (DSDV) [9] algorithm uses a serial number mechanism to distinguish the new and old degree of routes, only with the highest number of routes at a time, and the optimal route is selected if there are two routing serial numbers (for example, the shortest number). Ad hoc On-demand Distance Vector Routing (AODV) [10] is combined with the advantages of DSDV and support the multicast routing and improve network service quality. Nonetheless, DSDV and AODV have a notable disadvantage: they have no support for single-channel work, which will have a poor performance in a condition where network topology changes are faster. In some studies, OLSR [11] performed better than AODV via using a number of overhead packets to send messages from the source vehicle to the destination vehicle. Dynamic Source Routing (DSR) [12], as an on-demand algorithm, is also not appropriate for VANETs. It employs source routing other than depending on a transitional node routing table. However, its expansibility is largely limited. The multicast with ant colony optimization for VANETs based on MAODV (MAV-AODV) protocol [13] is based on the Multicast Ad hoc On-Demand Distance Vector (MAODV) [14] protocol and principles of the ant colony optimization (ACO). It is intended to improve the multicast structure life cycle and to realize the more efficient packet delivery with minimal transmission and management overheads. The M-AODV+ (an extension of the AODV+ routing protocol for supporting vehicle-to-vehicle communication) [15] routing protocol achieved high reliability in V2V communication; when it is impossible to realize multi-hop or single-hop communication in ad hoc networks, it creates another communication link between vehicles.

The MAR-DYMO [16] based on the ACO is applied to unicat routing in MANETs. It exploits the advantage of the DYMO [17] routing to regulate the behavior of ants, and chooses the best path and the most appropriate range of fault prevention. In some works, ant colony systems are applied to multicast routing optimization for wireless ad hoc networks based on mesh structure. For the DCMP, it is constantly looking for shorter routes (based upon the principles, they possess more pheromone) to accommodate these new best routes' mesh-based structures. Others have presented improvements to MAODV, such as considering the node mobility in the failure prediction [18], improving the multicast route's repair, or routing decision in dynamic node fluctuation environment. Menouar et al. proposed a routing protocol based on the predictive motion trajectory (movement prediction-based routing, MOPR) [19]. It is used to improve the GPSR [20] protocol, which takes the position, movement direction, and speed of the vehicles into consideration for routing path selection. Most of the previous vehicle communication studies have been limited to one-hop or few-hop communications [21], mainly to communicate with nearby upstream traffic vehicles to avoid collision [22,23]. Meanwhile, it is also very crucial to send data from a vehicle to a destination severeal miles away through multi-hop relay with multiple intermediate vehicles. Therefore, a multi-hop routing protocol is needed in a large vehicular network. VADD [8] and MDDV (mobility-centric data dissemination algorithm for vehicular networks) [24] are two multi-hop routing protocol in VANETs. In VADD and MDDV, road act as a link where data delivery depends upon the density of vehicles off the road. Therefore, data will be delivered along the shortest-delay path to the destination.

At present, most vehicles are fitted with GPS and navigation systems, making it possible to secure vehicle location The vehicle is fitted with pre-installed digital maps [25]. The installment of the preloaded digital map in a vehicle not only describes the topology of the road, but also collects traffic statistics such as vehicle density and average speed.

For the assessment of the routing protocol algorithms in VANETs by simulation, the Manhattan Mobility Model [26] has been studied. There are many kinds of mobility models in vehicular ad-hoc networks (VANETs). These mobility models lead the vehicle driver in selecting the right routing path also offer safety and comfort. One such mobility model is the Manhattan Mobility Model. This mobility model accepts a grid road typology and was mainly recommended for the movement in the urban area, where the streets are in an organized manner. In this mobility model, the mobile nodes move in a horizontal or vertical direction with an urban map. This is a great benefit in modeling movement in an urban area where a pervasive computing service among portable devices is provided. In this paper, we use the Manhattan Mobility Model to evaluate the proposed protocol algorithm, where the dynamics of the problem we are about to solve are captured.

## 3. An Opportunistic Routing for Data Forwarding Based on Vehicle Mobility Association

Vehicle communication is useful for supporting numerous vehicular applications that ensure the driver's safety and convenience. It is still a challenge to the VANETs [27]. Because of the rapid change of network topology, the high-speed movement and frequent network disconnection between vehicles have resulted in the invalidation of traditional network routing protocols [28]. An effective algorithm should be proposed to reduce delay and save space utilization in the case of a high data rate.

If the source vehicle (SV) wishes to send a message to the destination (DV). In the routing algorithm (AODV), the SV sends a packet to the neighbor vehicles and forwards until the packet reaches the DV. The DV implements the reverse path transmission information to the SV. This selection will reduce the data delivery ratio because it only lets the source vehicle send a request to the neighboring vehicles, but does not consider the network structure change of vehicles and the association between vehicles [29]. Therefore, vehicle network structure change and the association between vehicles are important to consider in data delivery path selection.

### *3.1. Definition and Analysis*

In most of the routing algorithms, the replica information is a type of routing overhead. OVMA preserves replica information and primarily records the degree of association between vehicles and the path of message passing. OVMA is designed as a two-phase algorithm:

- Information efficient region phase.
- Information efficient region boundary phase.

The replica information (exchange information, EM; response information, HM) and parameters definition are shown in Table 1:

- EM (Ev, Es, Ec, Er, $tabu_n$, Ert) represents exchange information, which means that the replica information is carried and can spread in a certain range.
- HM (Request) refers to the response information, which contains the response information and can spread in a certain range.

**Table 1.** Description of parameters. EM: exchange information.

| Parameter | Definition |
| --- | --- |
| Ev | Velocity vector |
| Ert | EM information lifetime |
| Es | Information source (base station) |
| $tabu_n$ | Tabu List |
| Ec | The degree of association between vehicles |
| Er | Data delivery path |
| Request | Determine whether to exchange EM information |

Suppose that the vehicles and the paths between vehicles can be abstracted into a graph theory problem of points and lines. The distance between vehicles can be acquired by GPS, and each vehicle carries EM and HM information and spreads in a fixed time.

Information efficient region phase: we can define a topological structure Graph G = (V, E), where V is the node in network, E is edge which can show as E = {$e_{ij}$ | $i \in$ V, $j \in$ V}, and $i$ and $j$ are nodes. $d_{ij}$ is weighted between $i$ and $j$.

We assume that the process of forwarding information about the network is always propagated along the optimal path and the propagation of information between the two nodes always first looks for the nearest node as the next hop information transmission node. The network information transfer rate from the $i$ node and the $j$ node: $\varpi_t[d_{ij}(t)]$. This can be expressed as the reciprocal of the weight of the $i$ node and the $j$ node.

$$\varpi_t[d_{ij}(t)] = \frac{1}{d_{ij}(t)} \tag{1}$$

Therefore, the efficiency of the whole network G: $\varpi_t$[G] can be defined as the average of the information transmission efficiency of each node, and there are $n$ nodes in the network.

$$\varpi_t[G] = \frac{1}{n(n-1)} \sum_{i \neq j \in G} \frac{1}{d_{ij}} \tag{2}$$

In vehicular networks, if a node is directly associated with many other nodes, the node is in the central position within the network. The degree of association between nodes is utilized to intuitively represent the role of nodes in the network. The influence of the association degree on the overall transmission efficiency of the network can be calculated by calculating the information centrality of the edges connected between nodes.

$\xi_{ij}(t)$ is the information centrality of the edge $e_{ij}$, which is defined as the relative reduction in the transmission efficiency of the entire network when the edge $e_{ij}$ is removed.

$$\xi_{ij} = \frac{\varpi_t[G] - \varpi_t[d_{ij}(t)]}{\varpi_t[G]} \tag{3}$$

Accordingly, the association degree between nodes function is formulated as Equation (4).

$$\delta_{ij}(t) = 1 - \xi_{ij}(t) \tag{4}$$

Supposing $v_i(t)$ and $v_j(t)$ are two arbitrary points at time $t$, $\gamma$ represents the frequent set of nodes with $i$ node that the degree of association greater than $\mu$ ($\delta_{ij}(t) > \mu$) at moment $t$. $\delta_{ij}(t)$ represents the degree of association among nodes. $\gamma$ can be expressed as:

$$\gamma = \{\delta_{ij}(t) > \mu | v_i, v_j \in V\} \tag{5}$$

At the initial time, each node has the same degree of association that recorded in Ec, $\delta_{ij}(t)$ = Q. The optimal solution of the data delivery can be achieved by the directed graph $g = (v, e, \gamma)$. Because the data delivery cannot be repeated through the same node, use $tabu_n$ table ($tabu_n(n = 1, 2, 3...n)$ to record the node passing information and dynamically adjusted time.

The transfer probability of data from the node $i$ to the node $j$:

$$p_{ij}(t) = \begin{cases} \dfrac{[\delta_{ij}(t)]^\alpha [\omega_{ij}(t)]^\beta}{\sum\limits_{i \neq s \in G} [\delta_{is}(t)]^\alpha [\omega_{is}(t)]^\beta} & j, s \notin tabu_n \\ 0 & j \in tabu_n \end{cases} \tag{6}$$

The transfer probability of data function depends on four parameters ($\delta_{ij}(t)$, $\omega_{ij}(t)$, $\alpha$, $\beta$), where $\alpha$ is the heuristic factor, which indicates the importance of the node perception information. $[\delta_{ij}(t)]^\alpha$ determines how densely and uniformly the nodes are distributed along the route. $\beta$ is the expected heuristic factor, which shows the relative importance of the visibility. $[\omega_{ij}(t)]^\beta$ represents the importance of the geographical distance. $\alpha$ and $\beta$ should satisfy $\alpha + \beta = 1$. The heuristic function is formulated as Equation (7):

$$\omega_{ij}(t) = \frac{1}{d_{ij}(t)} \tag{7}$$

It is obvious that the importance of vehicles of association is set as greater than the geographical distance in Equation (6). This is because if a nearer node is selected for data forwarding, data packets have to be carried by the nodes instead of being forwarded wirelessly to the next hop. As the wireless transmission is much faster than the vehicles' speed, this event causes more delays and an even smaller !data delivery ratio in the network.

On the other hand, the transfer probability of data function will be higher for lower values of the heuristic factor ($\alpha$). When the distribution of vehicles on the road follows a smaller density, the value of $\delta_{ij}(t)$ will be lower. When a road with lower vehicle density is supposed to forward the packets, the transfer probability of data will become lower. Therefore, Equation (6) is set to be higher for roads with greater vehicle density distribution with lower values of $d_{ij}(t)$ and higher values of $\delta_{ij}(t)$ that can guarantee the packets will be delivered with a lower delay in the networks.

Because the path information recorded by the Er table does not apply at any time, the Ec table information needs to be updated with the change of time. There are countless strategies for updating the Ec table information. We state that the message will be updated after the message is passed. For time $t + n$, given the following update rule:

$$\delta_{ij}(t + n) = |\delta_{ij}(t + n) - \delta_{ij}(t)| \tag{8}$$

Here, we define the $\delta_{ij}(t + n) = |\delta_{ij}(t + n) - \delta_{ij}(t)|$, which does not just update the Ec table under the existing data. $|\delta_{ij}(t + n) - \delta_{ij}(t)|$ can accurately reflect the change of the association degree between nodes.

Information efficient region boundary phase: Assume that there are two vehicles A and B, where vehicle A is located in the P information source region, and vehicle B is located in the Q information source region. Vehicles A and B broadcast their EM information to the surroundings from time to time and according to HM information to determine whether or not the EM information is exchanged [30].

The position relationship between vehicles A and B can be established by calculating the angle of movement direction, and whether or not they are in the same base station region. The position relationship of vehicles A and B can be calculated through the Ev vector of the EM message carried by each other to determine whether the two vehicles are traveling in the same direction or in opposite directions.

Here we use cosine similarity to calculate the directional relations between vehicles. The cosine similarity is also called the cosine distance. It is utilized as a measure of the magnitude as the difference between two individuals in the vector space. The vector is the direction along the line in the multidimensional space. If the two vectors are in the same direction (that is, the angle is close to zero), then the two vectors are parallel. In order to establish whether the two vectors direction is consistent, it is necessary to use the cosine theorem calculation vector angle. Compared to Euclidean distance, cosine distance pays more attention to the difference between the two vectors in the direction. With the help of the three-dimensional coordinate system to see the difference between the Euclidean distance and cosine distance:

It can be seen from the Figure 2 that the Euclidean distance is used to measure the absolute distance of each point in space, where each point with coordinates is directly related. The cosine distance measure is the angle between the vector space, more strongly reflecting differences in direction, rather than position. If the position of point A remains the same and point B has moved away from the origin of the axis, then the cosine distance cos θ is kept constant (because the angle does not change), and the distance between A and B is clearly changed. This represents the difference between Euclidean distance and cosine distance.

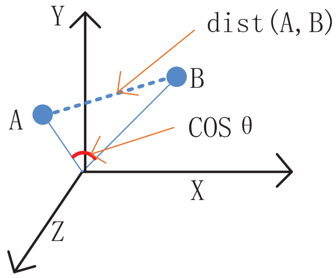


**Figure 2.** The difference between Euclidean distance and cosine similarity.

The calculation method is defined as follows:

$$\eta = \cos \frac{a.v * b.v}{|a.v||b.v|}$$

$$= \cos \frac{a.v.x * b.v.x + a.v.y * b.v.y}{\sqrt{(a.v.x^2 + a.v.y^2) * (b.v.x^2 + b.v.y^2)}} \tag{9}$$

where $a.v$ and $b.v$ represent the speed vector of vehicle A and vehicle B. $a.v.x$ and $b.v.x$ represent the speed of vehicles A and B in the $x$-axis direction vector. a.v.y and b.v.y represent the speed of vehicles A and B in the $y$-axis direction vector. $\sqrt{(a.v.x^2 + a.v.y^2) * (b.v.x^2 + b.v.y^2)}$ represents the velocity vector inner product. If $|\eta| < 10$ and vehicles in the same information source region indicate that the vehicles are traveling in the same direction, there is no exchange of duplicate information. If $|\eta| > 170$ and vehicles are in different information source regions, as the vehicles are traveling in opposite directions, then duplicate information is exchanged.

*3.2. Node Traversal Process*

As shown in Figure 3, let the $v_1$ be the source node which needs to send some messages to the destination node $v_{45}$. The implementation process of the algorithm based on Figure 2 is as follows:

At the initial state, all adjacent nodes are associated with equal degrees ($\delta_{ij}(t)$ = Q).

Step 1. Accessing neighboring nodes of the $v_1$ and calculating the data transfer probability. All nodes with a transition probability greater than $\tau$ ($p_{v_1,v_i}(t) > \tau$) are used as the next access node ($v_1 \rightarrow v_2$, $v_1 \rightarrow v_{11}$, $v_1 \rightarrow v_{16}$, $v_1 \rightarrow v_{12}$, $v_1 \rightarrow v_{36}$), and these nodes are recorded in the *tabu* table ($v_2, v_{11}, v_{16}, v_{12}, v_{36} \in tabu_n$).

Step 2. Accessing adjacent nodes of $v_2, v_{11}, v_{16}, v_{12}, v_{36}$ and calculating the data transfer probability. All nodes with a transition probability greater than $\tau$ ($p_{v_{2,11,16,12,36},v_i}(t) > \tau$) are used as the next access node ($v_2 \rightarrow v_9$, $v_{16} \rightarrow v_3$, $v_{12} \rightarrow v_3$, $v_{12} \rightarrow v_{10}$, $v_{36} \rightarrow v_5$), and the resulting nodes are recorded in the *tabu* table ($v_9$, $v_3$, $v_{10}$, $v_5 \in tabu_n$).

Step 3. Accessing adjacent nodes of $v_9$, $v_3$, $v_{10}$, $v_5$ by calculating the data transfer probability, finding all the nodes with a transition probability greater than $\tau$ ($p_{v_{9,3,10,5},v_i}(t) > \tau$) as the next node ($v_9 \rightarrow v_7$, $v_9 \rightarrow v_{13}$, $v_3 \rightarrow v_{14}$, $v_3 \rightarrow v_{23}$, $v_5 \rightarrow v_{34}$), and the resulting nodes are recorded in the *tabu* table ($v_7$, $v_{13}$, $v_{14}$, $v_{23}$, $v_{34} \in tabu_n$).

Step 4. Accessing adjacent nodes of $v_7$, $v_{13}$, $v_{14}$, $v_{23}$, $v_{34}$ by calculating the data transfer probability, finding all the nodes with a transition probability greater than $\tau$ ($p_{v_{7,13,14,23,34},v_i}(t) > \tau$) as the next node ($v_{14} \rightarrow v_{23}$, $v_{14} \rightarrow v_{29}$), and the resulting nodes are recorded in the *tabu* table ($v_{29} \in tabu_n$).

Because the $v_{23}$ node as the subsequent node $v_3$ has passed the message, $v_{23}$ has been accounted for in the tabu list. It will not be used to deliver the message again. Thus, the $v_{14}$ node in the $v_{23}$ node path will not deliver the message.

Step 5. Accessing adjacent nodes of $v_{29}$ by calculating the data transfer probability, finding all the nodes with a transition probability greater than $\tau$ ($p_{v_{29},v_i}(t) > \tau$) as the next node ($v_{29} \rightarrow v_{37}$, $v_{29} \rightarrow v_{39}$), and the resulting nodes are recorded in the *tabu* table ($v_{37}$, $v_{39} \in tabu_n$).

Step 6. Accessing adjacent nodes of $v_{39}$, $v_{39}$ by calculating the data transfer probability, finding all the nodes with a transition probability greater than $\tau$ ($p_{v_{39,37},v_i}(t) > \tau$) as the next node ($v_{39} \rightarrow v_{45}$), and the resulting nodes are recorded in the *tabu* table ($v_{45} \in tabu_n$).

Step 7. A set of the maximum data transfer probability nodes is found as the best path for this message, and the path is recorded in the Er table ($v_1$-$v_{12}$-$v_3$-$v_{14}$-$v_{29}$-$v_{39}$-$v_{45}$).

If a node data transfer probability greater than $\tau$ cannot be found, reduce the value of the data transfer probability ($p_{i,j}(t) > \varsigma$). Repeating these steps until a path with the largest data transfer probability is identified as transmitting this message.

Step 8. Computing adjacent node affinity for optimal path obtained ($\delta_{ij}(t) = 1 - \xi_{ij}(t)$), and the result is saved in Ec table.

If the Ert is sufficient, is still delivers messages in accordance with the above procedure. On the contrary, if Ert to the EM information lifetime, update EM info: Ev update to current speed vector, Es update as current information source, $tabu_n$ and Er update to an empty table. Ec records node association value updated to Q.

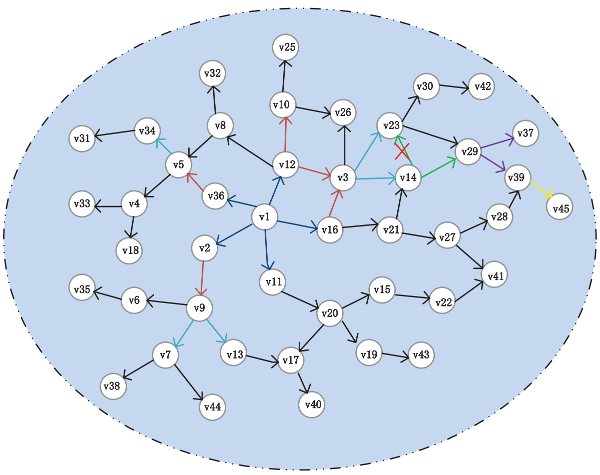


**Figure 3.** Brief introduction of OVMA (Opportunistic Routing for Data Forwarding Based on Vehicle Mobility Association).

### *3.3. The Algorithm Design of OVMA*

According to the previous section of the traversal process, we can see that OVMA algorithm implementation process is as follows:

If Ert is sufficient:

- A graph G(V, E), a source node $i$, initial state: $\delta_{i,j}(t) = \delta_{m,n}(t) = Q$;
- Accessing adjacent nodes of $i$ and calculating the data transfer probability, $p_{i,j}(t) > \tau$;
- If a node $s$ cannot be found, $p_{i,s}(t) > \tau$, reduce the value of $p_{i,s}(t) > \varsigma$ ($\varsigma > \tau$);
- Add $j, s$ in $tabu_n$, ($j$,$s$) $\in tabu_n$;
- Accessing adjacent nodes of $j$ and $s$ and calculating the data transfer probability;
- If $p_{j,s}(t) > \tau$, the algorithm is unable to execute, because $s \in tabu_n$;
- Add the data delivery path in Er to calculate adjacent node affinity, $\delta_{ij}(t) = 1 - \xi_{ij}(t)$, update Ec table.
- If node $i$ and node $j$ are located in information efficient region boundary, broadcast the EM information and calculate the angle between A and B: $\beta$;
- Feedback HM information to determine whether or not the EM information is exchanged.

Else:

- Update EM info: tabun = null, Er = null, Ec: $\delta_{i,j}(t) = \delta_{m,n}(t) = Q$

According to the above selected process, OVMA algorithm pseudo code can be obtained, as shown in Algorithms 1 and 2.

**Algorithm 1** Information efficient region phase

**Input:** A graph G(V, E), a source node $S$, a destination node $D$;
**Output:** optimal path and nodes association degree;

$\delta_{ij}(t)$: represents the degree of association between nodes
$p_{i,j}(t)$: the data transfer probability
Ert: EM information lifetime
$tabu_n$: tabu List
Ec: the degree of association between vehicles
Er: data delivery path
Initial state: $\delta_{i,j}(t) = \delta_{m,n}(t) = Q$
**for** i$\neq j \in g = (v, e, \gamma)$, j $\notin tabu_n$ **do**
    **if** Ert is sufficient **then**
        calculate the data transfer probability $p_{i,j}(t) > \tau$
        **if** cannot find a node s, $p_{i,s}(t) > \tau$ **then**
            reduce the value of $p_{i,s}(t) > \varsigma$ ($\varsigma < \tau$)
        **end if**
        add $j, s$ in $tabu_n$, $(j, s) \in tabu_n$
        **if** $p_{j,s}(t) > \tau$ **then**
            unable to execute, because s$\in tabu_n$
        **end if**
        add the data delivery path in Er
        calculate adjacent node affinity, $\delta_{ij}(t) = 1 - \xi_{ij}(t)$
        update Ec table
        $\delta_{ij}(t+n) = \Delta\, \delta_{ij}(t+n)$
        $\Delta\, \delta_{ij}(t+n) = |\, \delta_{ij}(t+n) - \delta_{ij}(t)|$
    **else**
        Ert to the EM information lifetime
        update EM info
        $tabu_n$ = null, Er = null
        Ec: $\delta_{i,j}(t) = \delta_{m,n}(t) = Q$
    **end if**
**end for**

**Algorithm 2** Information efficient region boundary phase

Es: information source (Base Station)
Ev: velocity vector
**for** $i \in G_1, j \in G_2$ **do**
    **if** Ert is sufficient **then**
        broadcast the EM information
        calculate the angle between A and B vehicles directions
        $\beta = \arccos \frac{a.v * b.v}{|a.v||b.v|}$
        **if** $|\beta| < 10$ **then**
            same direction
            **if** at the same Es **then**
                feedback HM information
                do not exchange EM information
            **end if**
        **end if**
        **if** $|\beta| > 170$ **then**
            different directions
            **if** at the different Es **then**
                feedback HM information
                exchange EM information
            **end if**
        **end if**
    **else**
        Ert to the EM information lifetime
        update EM info
    **end if**
**end for**

## 4. Performance Evaluation

In the OVMA algorithm, $\alpha$ and $\beta$ are the heuristic factor and the expected heuristic factor of nodes, which satisfy $\alpha + \beta = 1$. Change the value of $\alpha$ and $\beta$ and observe the performance of the algorithm. We compared OVMA with three existing VANETs routing protocol of Greedy Perimeter Stateless Routing (GPSR), Optimized Link State Routing (OLSR), and D-ODMRO. Data delivery ratio, routing overhead, and data delivery delay are used to evaluate the performance of OVMA. In the simulation, $\mu$ and $\tau$ are set to be greater than 0.5 in order to ensure the association between nodes and information forwarding probability, which can significantly improve the performance of experimental results. This simulation uses MATLAB as the simulation environment and the Manhattan Mobility Model for the vehicle's movement. For the Manhattan Mobility Model [31], the probability of forwarding movement is set to 0.5, and the probability of turning left or right is set to 0.25, respectively. It is remarkable that in IEEE 802.11P standards, the communication range of vehicles is confirmed according to the required data rate in the VANETs.

Table 2 summarizes the relevant parameters used for the simulation experiment of the proposed OVMA opportunistic routing protocol.

**Table 2.** Simulation Parameters.

| Parameters | Value |
|---|---|
| Mobility model | Manhattan Mobility Model |
| MAC and PHY Layers | IEEE 802.11P |
| Simulation time (s) | 1000 |
| Number of vehicles | 50, 150, 250, 350, 450 |
| Vehicle velocity (km/h) | 40–80 |
| Transmission range (m) | 300 |
| CBR (data per second) | 20–180 |
| EM size (bits) | 320 |
| HM size (bits) | 30 |

Figure 4 describes the impact of changing the $\alpha$ and $\beta$ values of the network lifetime. This simulation assumed that the network dies when half of the nodes within the network are depleted of energy. It can be observed that when the node heuristic factor $\alpha$ is increased, the energy consumption is considered more when selecting forwarding nodes, so the network lifetime can be extended. When the value of $\alpha$ is near 0.88, the network has the longest lifetime. When the $\alpha$ value is 0.88, OVMA ensures the connectivity and coverage on the network and balances the energy consumption of nodes, reducing the data traffic, saving the energy of the nodes, and prolonging the network lifetime. However, when the expected heuristic factor $\beta$ takes up a small proportion of calculated transmission rate, there is a degradation of the perceived performance of data forwarding, resulting in the existence of data across the network for a longer period of time, increasing the energy consumption of nodes and thus affecting the network lifetime.

The simulation results in Figure 5 depict the impact of changing the settings of $\alpha$ and $\beta$ on the data forwarding success ratio following consideration of the energy, delay, and routing overhead. When the $\alpha$ value is about 0.74, the network has the highest data forwarding success ratio. When the $\alpha$ value is 0.74, the greater the information heuristic performance, the better the perception between vehicles (which makes the association between vehicles increase), the data cannot pass too many redundant nodes during forwarding, and the network has the highest data forwarding success ratio.

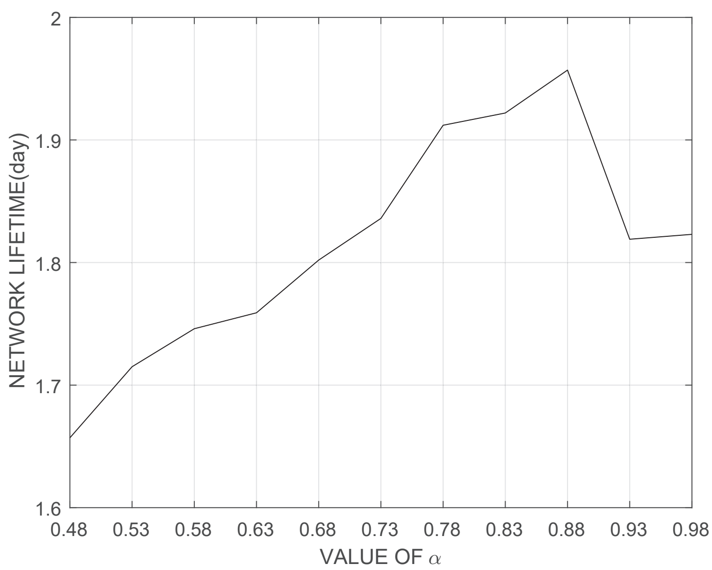


**Figure 4.** Network lifetimes vs. value of $\alpha$.

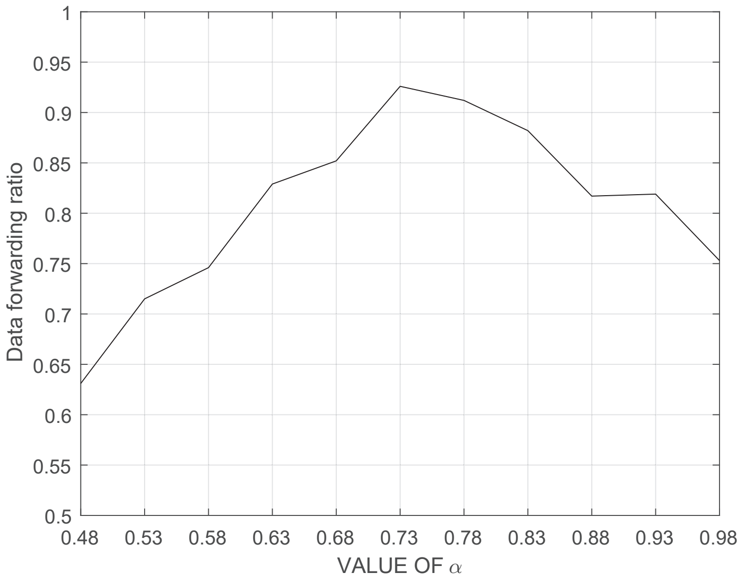


**Figure 5.** Data forwarding ratio vs. value of $\alpha$.

Figure 6 illustrates the impact of changes in $\alpha$ and $\beta$ on network routing overhead. The setting of replica information life (Ert) is to eliminate the impact of expired routes. It can be seen that with the change of $\alpha$ value, the routing overhead varies slowly when the $\alpha$ value is less than 0.78. The OVMA protocol can effectively reduce route establishing time, route recovery time, and route overload, and the packet delivery ratio remains high.

Figure 7 shows the impact of changing the setting of $\alpha$ and $\beta$ on data forwarding delay. Often, the paths can be congested and there may be accidents, natural disasters, or business disputes that can cause transmission delays. Responding to requests by a vehicle with a larger association improves responsiveness by reducing network hops and network latency. When the value of $\beta$ is greater than 0.22, the data forwarding delay varies steadily.

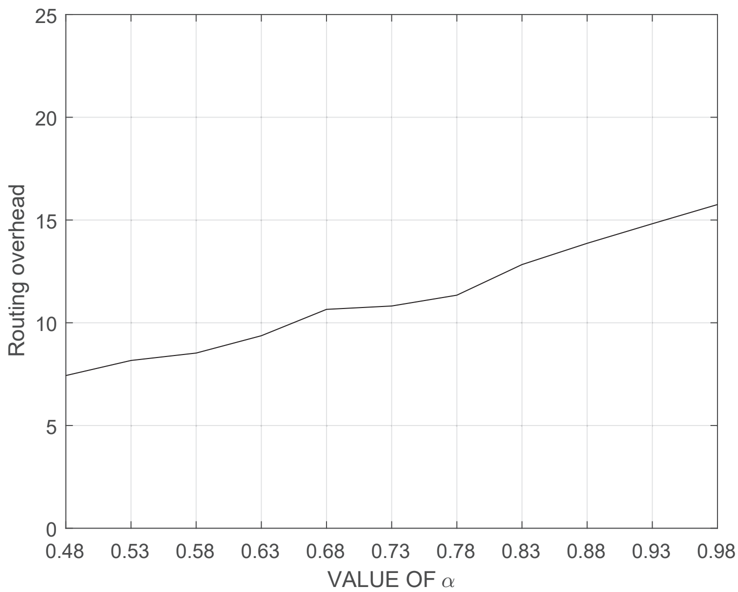


**Figure 6.** Routing overhead vs. value of $\alpha$.

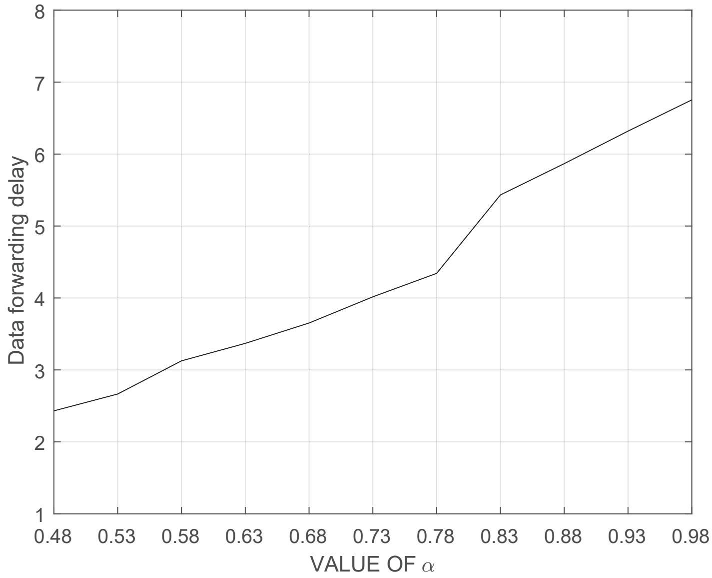


**Figure 7.** Data forwarding delay vs. value of $\alpha$.

The analysis of the data delivery ratio metric is shown in Figure 8. It describes the degree to which data are delivered successfully.

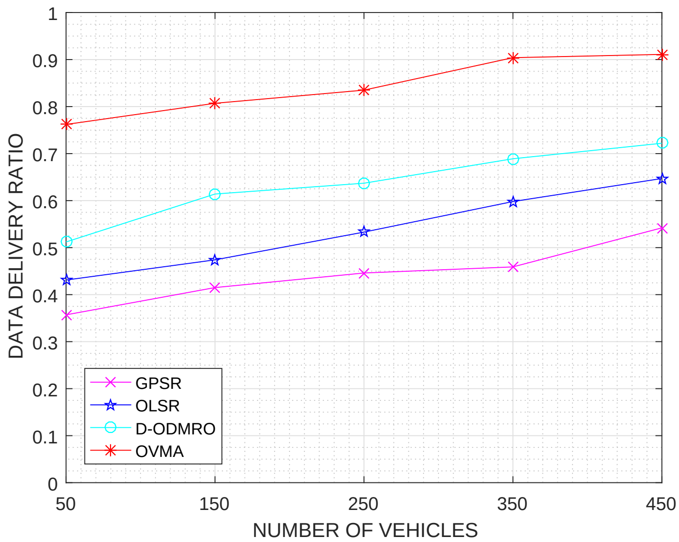


**Figure 8.** Data delivery ratio vs. number of vehicles for different algorithms. GPSR: Greedy Perimeter Stateless Routing; OLSR: Optimized Link State Routing; D-ODMRO: destination driven on demand multicast routing protocol.

As shown in Figure 8, in this metric respect, OVMA achieved a better performance than DSR, MAV-AODV and OSTD. When the number of vehicles increases, the data delivery ratio of OVMA becomes more stable. This is because of the exchange of replica information (EM.HM) and because the degree of association between vehicles can ensure the rapid delivery of data.

The routing overhead metric is shown in Figure 9. Routing overhead covers all route discovery and route maintenance control messages. This parameter reflects the routing overhead caused by the routing protocol. Due to the low bandwidth of the ad hoc network, routing overhead directly affects the effective transmission rate of the network.

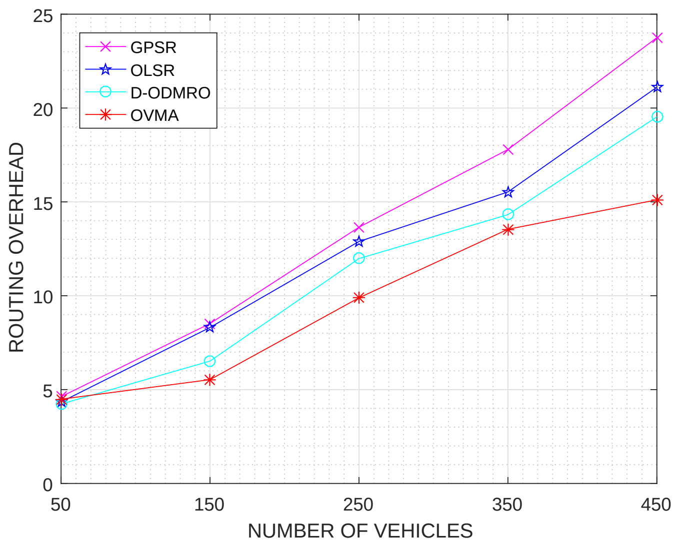


**Figure 9.** Routing overhead vs. number of vehicles for different algorithms.

According to Figure 9, when there are very few vehicles, OVMA has a higher routing overhead than the other three. On the contrary, when there are a large number of vehicles, the OVMA was slightly better than the other three because the route discovery becomes faster with a high route maintenance control.

The data delivery delay metric is shown in Figure 10. The data delivery delay is primarily reflected in the data-storage time for the node. If the data passes through the intermediate nodes in the transmission from the source to the destination, the data are frequently stored and forwarded to the intermediate node so that the transmission delay is too long, which will inevitably affect the communication efficiency.

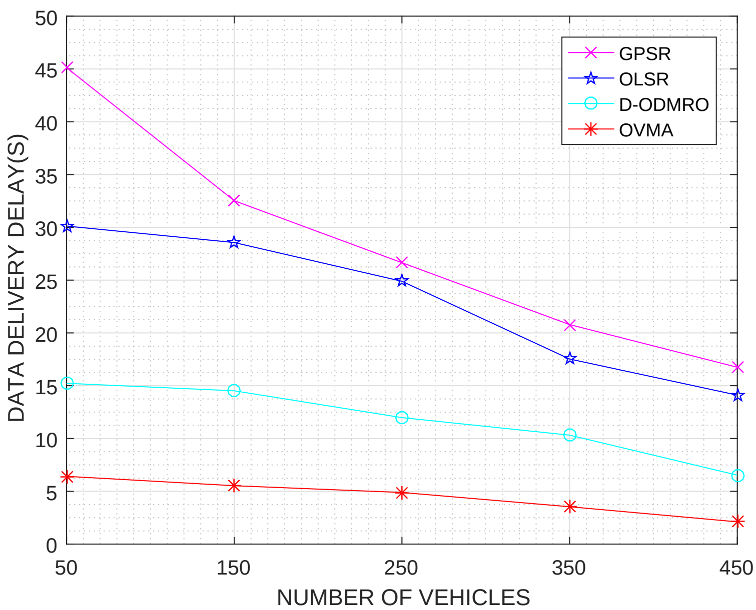


**Figure 10.** Data delivery delay vs. number of vehicles for different algorithms.

According to Figure 10, OVMA achieved better performance due to the OVMA passing data by determining the degree of association and data-transfer probability between vehicles. It can enable the fast transfer of data from the source into the destination without the need to transmit to too many intermediary vehicles.

As is clear from Figure 11, the routing overhead of OVMA increases gradually as the number of vehicles increases. As the number of vehicles increases, the frequency of routing is greater. As a result, the path discovery is relatively slow by the relative increase in the number of nodes by passing messages.

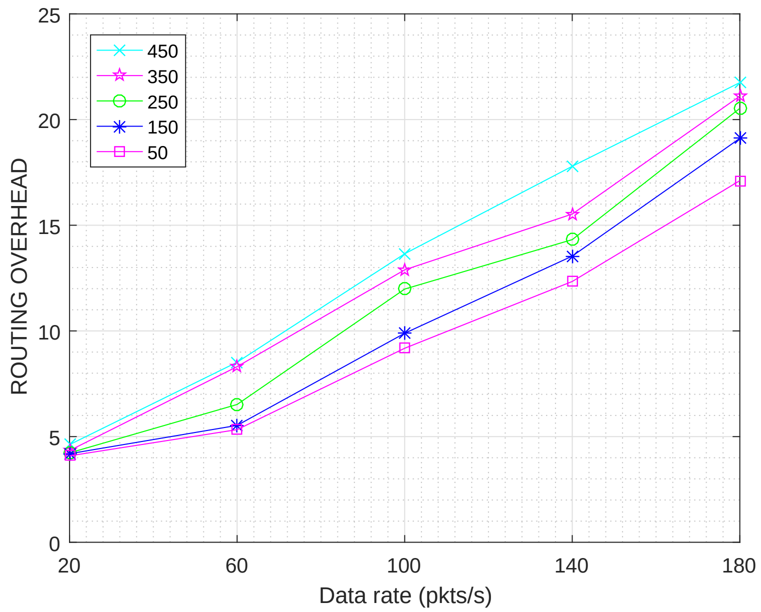


**Figure 11.** Routing overhead vs. data rate with different numbers of vehicles (50, 150, 250, 350, 450).

## 5. Conclusions

This paper applied the mobility association of the vehicle to find an optimal data transmission path, achieving fast data forwarding and transmission function in a low-delay situation. This strategy was implemented and evaluated in a new opportunistic routing protocol for vehicular ad hoc networks called OVMA, which comprises two phases: an information efficient region phase and an information efficient region boundary phase. The use of the vehicle mobility association brings about high-speed and high-performance data forwarding in the case of low data delay and routing overhead. For vehicles which are at the boundary of an information efficient region, whether or not to exchange the replica information is judged by the angle between their moving directions and the source of information they are currently in. From the simulation results, we observed that the OVMA had a better performance than GPSR, OLSR, and D-ODMRO. There were improvements in the data delivery ratio, routing overhead, and data delay metrics. We conclude that the OVMA algorithm can not only maintain a high data delivery ratio, but also maintain the stable transmission of network information, without being influenced by node caches and the area of information perception.

As a future work, we will consider more factors that affect network performance, such as bandwidth, network load, and so on. We will analyze the impact of these network factors on the network performance to improve the vehicle network routing algorithm in the present paper.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| DSRC | Dedicated short range communication |
| WAVE | Wireless access in a vehicular environment |
| GPRS | General Packet Radio Service |
| EDGE | Enhanced Data Rate for GSM Evolution |
| LTE | Long Term Evolution |
| NEMO | Network mobility |
| VADD | Vehicle-Assisted Data Delivery |
| MDDV | Mobility-centric data dissemination algorithm for vehicular networks |
| DSDV | Destination-Sequenced Distance-Vector Routing |
| AODV | Ad hoc On-demand Distance Vector Routing |
| OLSR | Optimized Link State Routing |
| DSR | Dynamic Source Routing |
| MAODV | Muticast ad hoc ondemand vetor |
| MAV-AODV | Multicast with ant colony optimization for VANETs based on MAODV protocol |
| M-AODV+ | An extension of AODV+ routing protocol for supporting vehicle-to-vehicle communication |
| MAODV | Multicast ad hoc on-demand distance vector protocol |
| MAR-DYMO | Mobility-aware Ant Colony Optimization Routing DYMO |
| DCMP | Distributed Cycle Minimization Protocol |
| GPSR | Greedy perimeter stateless routing |
| D-ODMRO | destination driven on demand multicast routing protocol |
| CBR | Constant bitrate |
| GPS | Global Positioning System |
| EM | Exchange information |
| HM | Response information |

## References

1. Wu, J.; Chen, Z. Human Activity Optimal Cooperation Objects Selection Routing Scheme in Opportunistic Networks Communication. *Wirel. Person. Commun.* **2017**, *95*, 3357–3375.
2. Barros, J. How to Build Vehicular Networks in the Real World. In Proceedings of the ACM International Symposium on Mobile Ad Hoc Networking and Computing, Philadelphia, PA, USA, 11–14 August 2014; pp. 123–124.
3. Sharef, B.T.; Alsaqour, R.A.; Ismail, M. Vehicular communication ad hoc routing protocols: A survey. *J. Netw. Comput. Appl.* **2014**, *40*, 363–396.
4. Dua, A.; Kumar, N.; Bawa, S. A systematic review on routing protocols for Vehicular Ad Hoc Networks. *Veh. Commun.* **2014**, *1*, 33–52.
5. Kim T, Kim I H, Sun Y, Jin, Z. Physical Layer and Medium Access Control Design in Energy Efficient Sensor Networks: An Overview. *IEEE Trans. Ind. Inf.* **2015**, *11*, 2–15.
6. Cao, Y.F.; Cheung, S.W.; Yuk,T.I. A Multiband Slot Antenna for GPS/WiMAX/WLAN Systems. *IEEE Trans. Antennas Propag.* **2015**, *63*, 952–958.
7. Zhang, Z.; Boukerche, A.; Pazzi, R. A Novel Multi-Hop Clustering Scheme for Vehicular Ad-Hoc Networks. In Proceedings of the Mobiwac'11 ACM International Workshop on Mobility Management and Wireless Access, Miami, FL, USA, 31 October–4 November 2011; pp. 19–26.

8. Zhao, J.; Cao, G. VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc, Networks. *IEEE Trans. Veh. Technol.* **2006**, *57*, 1910–1922.
9. Yang, X.; Sun, Z.; Miao, Y.; Wang, N.; Kang, S.; Wang, Y.; Yang, Y. Performance Optimisation for DSDV in VANETs. In Proceedings of the Uksim-Amss International Conference on Modelling and Simulation, Cambridge, UK, 25–27 March 2016.
10. Abbas, N.I.; Ilkan, M.; Ozen, E. Fuzzy approach to improving route stability of the AODV routing protocol. *EURASIP J. Wirel. Commun. Netw.* **2015**, *2015*, 1–11.
11. Toutouh, J.; Garcia-Nieto, J.; Alba, E. Intelligent OLSR Routing Protocol Optimization for VANETs. *IEEE Trans. Veh. Technol.* **2012**, *61*, 1884–1894.
12. Johnson, D.B. The Dynamic Source Routing Protocol for Mobile Ad Hoc Networking (DSR). Internet-Draft, draft-ietf-manet-dsr-09.txt, 2003.
13. Souza, A.B.; Celestino, J.; Xavier, F.A.; Oliveira, F.D.; Patel, A.; Latifi, M. Stable Multicast Trees Based on Ant Colony Optimization for Vehicular Ad Hoc Networks. In Proceedings of the 2013 International Conference on Information Networking (ICOIN), Bangkok, Thailand, 28–30 January 2013; pp. 101–106.
14. Royer, E.M.; Perkins, C.E. Multicast Operation of the ad-hoc on-Demand Distance Vector Routing Protocol. In Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking, Seattle, Washington, DC, USA, 15–19 August 2001; pp. 207–218.
15. Wantoro, J.; Mustika, I.W. M-AODV+: An Extension of AODV+ Routing Protocol for Supporting Vehicle-to-Vehicle Communication in Vehicular ad hoc Networks. In Proceedings of the IEEE International Conference on Communication, Networks and Satellite, Jakarta, Indonesia, 4–5 November 2014; pp. 39–44.
16. Correia, S.L.O.B.; Celestino, J.; Cherkaoui, O. Mobility-Aware Ant Colony Optimization Routing for Vehicular ad hoc Networks. In Proceedings of the Wireless Communications and Networking Conference, Cancun, Quintana Roo, Mexico, 28–31 March 2011; pp. 1125–1130.
17. Billington J, Yuan C. On Modelling and Analysing the Dynamic MANET On-Demand (DYMO) Routing Protocol. In *Transactions on Petri Nets and Other Models of Concurrency III*; Springer: Berlin, Germany, 2009.
18. Chen, X.; Zhong, Q.; Liu, D. An Improved MAODV Protocol Based on Mobility Prediction and Self-Pruning Flooding. In Proceedings of the WRI International Conference on Communications and Mobile Computing, Yunnan, China, 6–8 January 2009; pp. 127–131.
19. Menouar, H.; Lenardi, M.; Filali, F. Movement Prediction-Based Routing (MOPR) Concept for Position-Based Routing in Vehicular Networks. In Proceedings of the Vtc-2007 Fall Vehicular Technology Conference, Baltimore, MD, USA, 30 September–3 October 2007; pp. 2101–2105.
20. Karp, B.; Kung, H.T. GPSR: Greedy Perimeter Stateless Routing for Wireless Networks. In Proceedings of the International Conference on Mobile Computing and Networking, Boston, MA, USA, 6–11 August 2000; pp. 243–254.
21. Gomez, A.E.; Glaser, S.; Alayli, Y.; Neto, A.D.M.; Wolf, D.F. Cooperative Collision Warning for Driving Assistance. In Proceedings of the IEEE International Conference on Intelligent Transportation Systems, Rio de Janeiro, Brazil, 1–4 November 2016; pp. 990–997.
22. Saleh, A.I.; Gamel, S.A.; Abo-Al-Ez, K.M. A Reliable Routing Protocol for Vehicular Ad hoc Networks. *Comput. Electr. Eng.* **2016**, doi:10.1016/j.compeleceng.2016.11.011.
23. He Y, Xu W, Lin X. A Stable Routing Protocol for Highway Mobility over Vehicular Ad-Hoc Networks. In Proceedings of the IEEE Vehicular Technology Conference, Glasgow, UK, 11–14 May 2015; pp. 1–5.
24. Wu, H.; Fujimoto, R.; Guensler, R.; Hunter, M. MDDV: A Mobility-Centric Data Dissemination Algorithm for Vehicular Networks. In Proceedings of the ACM International Workshop on Vehicular Ad Hoc Networks, Philadelphia, PA, USA, 1 October 2004; pp. 47–56.
25. Li, J.; Song, N.; Yang, G.; Li, M.; Cai, Q. Improving positioning accuracy of vehicular navigation system during GPS outages utilizing ensemble learning algorithm. *Inf. Fusion* **2017**, *35*, 1–10.
26. Ramadhani, P.E.; Setiawan, M.D.; Yutama, M.A.; Perdana, D.; Sari, R.F. Performance Evaluation of Hybrid Wireless Mesh Protocol (HWMP) on VANET Using VanetMobiSim. In Proceedings of the International Conference on Computational Intelligence and Cybernetics, Makassar, Indonesia, 22–24 November 2017; pp. 41–46.
27. Mirjazaee, N.; Moghim, N. An opportunistic routing based on symmetrical traffic distribution in vehicular networks. *Comput. Electr. Eng.* **2015**, *47*, 1–12.

28. Hirose, T.; Makino, T.; Taniguchi, M.; Kubota, H. Activation Timing in a Vehicle-to-Vehicle Communication System for Traffic Collision. In Proceedings of the SAE 2016 World Congress and Exhibition, Detroit, MI, USA, 12–14 April 2016.
29. Wu, J.; Chen, Z. Data Decision and Transmission Based on Mobile Data Health Records on Sensor Devices in Opportunistic Networks. *Wirel. Person. Commun.* **2016**, *90*, 2073–2087.
30. Qing-song, C.A.I.; Chang, N.J.W.L. Adaptive Data Dissemination Algorithm for Vehicular Opportunistic Networks. *Comput. Sci.* **2011**, *38*, 58–63.
31. Zhou, B.; Xu, K.; Gerla, M. Group and Swarm Mobility Models for Ad Hoc Network Scenarios Using Virtual Tracks. In Proceedings of the Military Communications Conference, Monterey, CA, USA, 31 October–3 November 2004; Volume 1, pp. 289–294.