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A Distributed Routing Protocol and Handover Schemes in Hybrid Vehicular Ad Hoc Networks

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Abstract—**Vehicular Ad Hoc Networks (VANETs) have received considerable attention in recent years. VANETs provide many services and applications such as Internet access Voice over Internet Protocol (VoIP) and information dissemination. Due to dynamic changes in the network topologies, various routing protocols have been studied in the vehicular environments. However, the communications between source and destination vehicles involve many intermediate vehicles, and due to the high mobility of vehicles, these communication links become disconnected. In this paper, we propose a distributed routing protocol in VANETs with the help of roadside units (RSUs). The proposed scheme includes vehicle registration, finding the location of destination vehicle and the handover maintenance. The simulation results show that our proposed protocol is suitable for vehicles communications in VANETs.**

Keywords-distributed protocol; handover; VANETs; wireless communications

I. INTRODUCTION

In recent years, vehicular ad hoc networks (VANETs) are emerging technologies designed to improve road safety and traffic efficiency and to allow for the implementation of infotainment applications through Intelligent Transportation Systems (ITS) [1]. The VANETs provide both inter-vehicle communication and roadside-to-vehicle communication [2][3]. Inter-vehicle communication is supported by on board units (OBUs) which provide the interface for wireless communications among vehicles. Roadside-to-vehicle communication is sustained by roadside units (RSUs) which provide wireless coverage and network access for OBUs. The dedicated short-range communication (DSRC) between transceivers in VANETs is defined in IEEE 802.11p [4] and Wireless Access in Vehicular Environments (WAVE) [5]. The OBUs and RSUs equipped with DSRC can support different applications and provide a variety of services to users in vehicular environments.

The dynamic nature of vehicles in the network makes finding and maintaining routes in VANETs very challenging. Many applications are based on routing problems which are important issues both in the research community and the automotive industry. Voice over Internet Protocol (VoIP) is a general term of transmission technologies for the delivery of voice communications over IP networks. When the VoIP system is employed in VANETs, route lifetime between a source vehicle and a destination vehicle needs to be prolonged. In this paper, we focus on designing a routing protocol that extends the lifetime of the communication links between a source vehicle and a destination vehicle in VANETs with assistance of RSUs.

VANETs have general properties with mobile ad hoc networks (MANETs) such as short transmission range about 250-300 meters, distributed decisions and self-configuring operations, and path loss problems. VANETs and MANETs have some differences: (1) vehicles in VANETs are moving faster than nodes in MANETs, (2) VANETs frequently change network topologies, and (3) the batteries in vehicles can be recharged but nodes have power source restrictions [6]. As a result, some routing protocols in MANETs are not suitable in VANETs. In VANETs, the routing protocols include: (1) routing protocol without RSUs (e.g. VADD [7] and CAR [8]), and (2) routing protocol with RSUs (e.g. RAR [9] and DRR [10]).

The proposed protocol main focus is how to construct a reliable routing path from a source vehicle to a destination vehicle. Additionally, we need to adjust the route to extend the route lifetime between the source and destination vehicles. Wireless network services are ubiquitous. Drivers can receive information and download files by attaching an embedded computer in a vehicle. Because the transmission range of vehicles and RSUs is limited, to extend the service range of RSUs is important [11]. We designed a distributed routing protocol to consider the communication interaction between vehicles and RSUs. Our protocol can achieve low communication overhead and provide high packet delivery ratio between source and destination vehicles. Our method consists of three phases. First, each vehicle will register its current location to a RSU whenever it finds a RSU different from its previous registered RSU. Second, the source vehicle broadcasts the routing requests to its nearby RSU which finds the current location of the destination vehicle. A routing path from source vehicle to destination vehicle can be established through the implementation of our protocol. Finally, we shall maintain the handover between vehicles and RSUs to extend the route lifetime of source and destination vehicles. The simulation results show that our protocol has lower communication overhead and higher packet delivery ratio than previous work.

The rest of this paper is organized as follows. Section 2 describes the related works of routing protocols in VANETs. Section 3 presents our routing protocol. Section 4 shows the performance of our protocol through simulations. Finally, Section 5 concludes this paper.

II. RELATED WORK

The VANETs provide a variety services to drivers and passengers such as safety and infotainment applications. These applications need to perform data dissemination. Different routing protocols are designed for data dissemination

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between a source and a destination vehicle. However, a source vehicle does not have the location information about a destination vehicle. Location services are aimed to discover the location of a destination vehicle. Many routing and location service protocols have been proposed for VANETs. Some of the routing protocols further provide a location service and find a routing path between a source and a destination.

The location service protocols can be divided into hierarchical-based and hash-based location services. RLSMP [12] is one of the hierarchical-based location service protocols. A source vehicle sends queries to the local RSU which is a cluster in a grid. The query is forwarded in spiral cells around the RSU until the location of the destination is found. VLS [13] is one of the hash-based location service protocols. Every vehicle has a corresponding position in a region by using a hash function. The closest vehicle of the position is serving as a location server. Source sends a query to destination's location server and then the location server forwards it to destination. However, sending queries to the destination by visiting all cells around the RSU increase the query response time. When a location server leaves the position, it needs to transfer location information to a new location server; the process incurs a high cost in overhead.

Recently, many routing protocols have been proposed for VANETs such as RBVT [14], CAR [8], VADD [7], and MOPR [15]. Vehicles in the aforementioned schemes broadcast periodic "*hello*" beacons with information about their moving directions and speeds. Vehicles collect and save neighbors' information in their tables. RBVT protocol uses real-time vehicular traffic information to create road-based paths consisting of succession of road intersections that have high probability of network connectivity among them. CAR finds connected paths between source and destination by considering vehicular traffic, and uses "guards" to adapt to movements of nodes. VADD uses not only opportunistic forwarding to transport data from a source to destination vehicle but also historic data traffic flow to determine the best route to the destination. MOPR selects the next hop vehicle based on the vehicles' moving directions and speeds to extend the lifetimes of the links between the vehicle and its neighbors. However, all of the aforementioned works need real-time vehicular traffic information. Vehicles maintain inter-vehicle connection based on periodical beacons thus increasing the routing overhead in VANETs.

DRR [10] and RAR [9] establish routing paths from a source to destination vehicle in hybrid VANETs. Vehicles propagate data not only via vehicle-to-vehicle but also via vehicle-to-infrastructure communication to a destination vehicle. DRR provides multiple differentiated reliable paths between a source vehicle and a destination vehicle for different applications. RAR introduces a novel affiliation method to affiliate a vehicle to several RSUs, and a single phase routing framework has been developed for hybrid VANETs. However, these two routing protocols do not consider extending the service range of RSUs. In other words, these protocols do not apply handover scheme between vehicles and RSUs which could adversely cause a decrease in packet delivery ratio and route lifetime from a source to destination vehicle.

In our proposed routing protocol, it utilizes the infrastructure provided by the RSUs and also the ad-hoc connectivity of vehicles. A source vehicle that needs the location information about a destination vehicle, it just sends requests to the home RSU and to the registered RSU of the destination vehicle. This process has a lower cost in overhead than that produced by visiting all RSUs in the network. Otherwise, we use distributed characteristics to design a methodology in which vehicles rebroadcast routing requests under certain conditions and not only on receiving and forwarding the information. Within considering this property, we avoid the periodical beacons and reduce the routing overhead for finding a route. We consider interactions between vehicles and RSUs; namely vehicles would perform handover scheme with RSUs. Applying this scheme, it would provide long route lifetime and high packet delivery ratio from a source to destination vehicle.

III. OUR PROTOCOL

In this section, we propose a distributed routing protocol in VANETs. With the assistance of RSUs, a source vehicle can efficiently search for the location of a destination vehicle. In order to prolong the route lifetime, when vehicles drive closely to or is away from a RSU, they will claim a handover request to adjust their routing path. The details of the proposed protocol are described as follows.

A. Vehicles Registration

In our vehicular environment, each RSU has a unique ID and accesses to the backbone networks such as Ethernet. RSUs broadcast advertisements periodically so vehicles can register them. We assume vehicles are equipped with embedded computers which can transmit and receive packets and vehicles already know the destination vehicle's ID. A vehicle knows the road topology and the positions of RSUs through a digital map. A vehicle also knows its own location in the network via GPS devices. The standard, 802.11p, defines the communication range of vehicles and RSUs at 250 to 300 meters. The packet delivery information such as source ID, destination ID, RSU ID, packet generation time, time-to-live (TTL), and other data is specified by the source vehicle and placed in the message header.

When a vehicle receives the advertisement of a RSU, the vehicle will register with the RSU and the RSU sends the vehicle's current location to its home RSU. Vehicles have a preloaded digital map in the embedded computer. The digital map is divided into several regions and there is at least one RSU in a region, whereas each vehicle has only one home RSU. As shown in Fig. 1, each RSU serve one region. Initially, each vehicle is assigned a single home RSU by hashing the vehicle ID. In the hash function, a vehicle ID is divided by the total number of all RSUs and the remainder is the home RSU ID. When a vehicle receives a control packet from a RSU which broadcasts an advertisement periodically, it registers its ID and location information to this RSU. The RSU is called the registered RSU of the vehicle. The

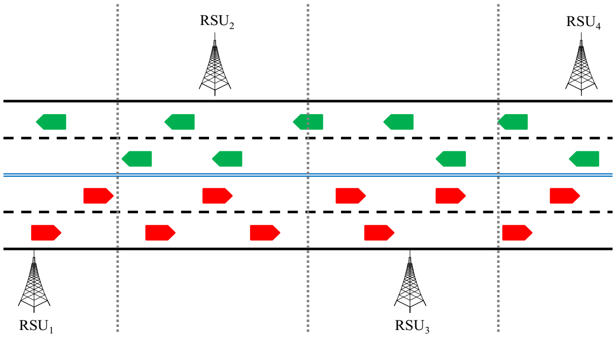

Figure 1. The VANETs with RSUs.

registered RSU knows the home RSU of the vehicle by its ID and the hash function. The registered RSU sends its ID and the vehicle's ID to the vehicle's home RSU via the backbone network. The home RSU searches the vehicle ID in its table and updates the vehicle's registered RSU ID.

B. *Forwarding Requests*

We utilize the distributed characteristic in that a vehicle can determine a back-off time [16] to send routing requests. A source vehicle will broadcast routing requests to the nearest RSU by computing distances of all RSUs via the preloaded digital map. When senders broadcast routing requests, in order to reduce communication overhead, the receivers which are the closest to the nearest RSU are responsible for rebroadcasting the routing request. Receivers wait for a back-off time before forwarding routing requests. Receivers which are closer to the nearest RSU have shorter back-off time than other receivers. In order to avoid packets collision, receivers will select a random number to determine the time before rebroadcasting the route request. When multiple receivers have overheard the same routing request before the corresponding back-off time being expired, receivers drop received routing requests and stop counting down the back-off time. The back-off time, $W_b(dist)$, is defined in (1).

$$W_b(dist) = \left(\left\lfloor \frac{R - dist}{l} \right\rfloor \times \alpha + rand\_number \right) \times time\_slot \quad (1)$$

where *dist* denotes the distance from the receiver to the sender, R denotes the largest communication radius of VANETs (250 meters in simulations), l (50 meters in simulations) and α (10 in simulations) are two parameters, *rand_number* is random number from 0 to 9, and *time_slot* denotes the duration from broadcasting a message to receiving it by others (1 ms in simulations). When receivers rebroadcast the routing request, they will record the vehicle ID from which the request was transmitted, thus each receiver will record the previous vehicle ID. Vehicles will continue above steps until the route request reaches the nearest RSU from the source vehicle. Fig. 2 shows an example of selection back-off time. When sender broadcasts a routing request, receiver$_1$ will selects 16 time slots (random number is 6) to be its back-off time, receiver$_2$ will select 32 time slots (random number is 2) to be its back-off time, and receiver$_3$ will select 11 time slots (random number is 1) to be its back-off time.

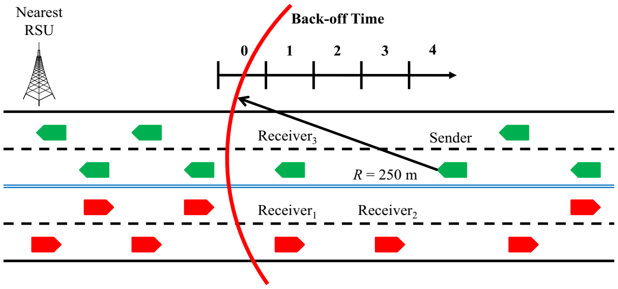

Figure 2. The back-off time of receivers.

The nearest RSU upon receiving the route request computes the destination's home RSU according to the destination ID and the hash function. After the home RSU receives the routing requests from the nearest RSU via the backbone network, the home RSU searches the current registered RSU of the destination ID. The registered RSU will receive the routing requests from the home RSU. The current registered RSU performs a local flooding to find the destination vehicle. The local flooding method is similar to a source vehicle sending routing requests to a RSU. The registered RSU starts to broadcast routing requests to its neighbor vehicles. The registered RSU can estimate the position of the destination vehicle by its registered information and broadcast the estimated location to neighbor vehicles. Each receiver will determine a back-off time according to the distance between it and the destination vehicle. The receivers closer to the destination vehicle have higher priority to rebroadcast routing requests.

Furthermore, in order to avoiding broadcasting routing requests indefinitely, TTL is added to the packet header and restricts the number of rebroadcasts. Vehicles will continue processing above steps until the destination vehicle receives the routing requests. Finally, if the destination vehicle is in the transmission range of the RSU, it sends a reply to the RSU immediately. On the other hand, if the destination vehicle is not in the transmission range of the RSU, it sends a reply to the RSU via the reverse path of the request packet. The path only goes through the registered RSU of the destination vehicle and the nearest RSU of the source vehicle. By sending the reply, intermediate vehicles and the source vehicle will record the next vehicle ID which sends the reply to them in order to transmit data to specific vehicles. After the source vehicle receives the reply successfully, it starts to transmit data to the destination vehicle. Fig. 3 shows an example of searching destination location, where source sends a request to RSU$_2$, and RSU$_2$ sends the request to RSU$_4$ which is Home RSU of destination, and RSU$_4$ sends the request to RSU$_3$ which is the Registered RSU of destination, and RSU$_3$ performs a local flooding to search for the destination.

C. *Handover Schemes*

A source vehicle, intermediate vehicles and a destination vehicle have to adjust the route to a RSU dynamically when they are close to a RSU or away from a RSU. In the following, we focus on two kinds of handover: intra-RSU handover and inter-RSUs handover. There are two scenarios in intra-

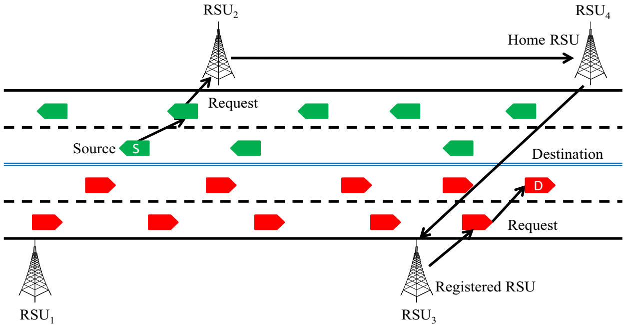

Figure 3. The routing request path from source to destination.

RSU handover: (1) A sender vehicle changes its next-hop neighbor from a vehicle to a RSU if the sender can connect to the RSU directly. (2) A sender vehicle changes its next-hop neighbor from a RSU to a vehicle due to the sender drives away from the RSU. Each vehicle knows its previous-hop vehicle or RSU and next-hop vehicle or RSU in order to transmit packets and to send replies to a specified receiver. In the route, vehicles may get periodical advertisements from a connected RSU and can use the Received Signal Strength Indicator (RSSI) to determine the link quality between vehicles and the connected RSU. According to the RSSI, the link quality can be assigned to one of the following four values.

When a vehicle cannot receive advertisements from any RSU, the vehicle determines its link quality to "00". When a vehicle receives advertisements from a RSU, the vehicle computes the RSSI. If the RSSI is above the desired threshold, the vehicle determines that the signal from the RSU is strong and it changes its link quality to "11". If the RSSI is below the desired threshold, the vehicle will check the previous stored link quality. If the previous stored link quality is "00", the vehicle knows that signal from the RSU is from weak to strong and it changes its link quality to "01". Otherwise, if the previous stored link quality is "11", the vehicle realizes that signal from the RSU is from strong to weak and it changes its link quality to "10". After deciding the link quality, vehicles will add their link qualities to the packet header when transmitting packets. As shown in Fig. 4, the sender has the link quality as "00" and the receiver has the link quality as "11". Additionally, link qualities are determined by the direction of vehicles. When vehicles are in the same position of different lanes, they may decide different link qualities. As shown in Fig. 4, the vehicle$_1$ has the link quality as "10" and the vehicle$_2$ has the link quality as "01".

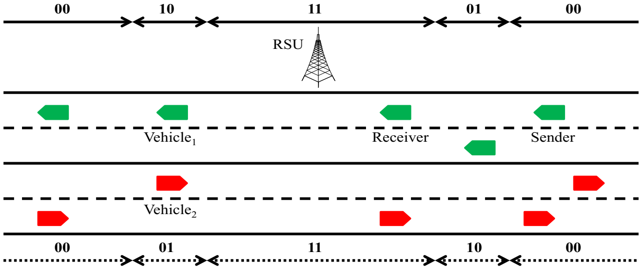

Figure 4. The possible link qualities of vehicles to RSU.

Intermediate vehicles will dynamically adjust a route from source to RSU by checking the received packet's link quality against their own link qualities. In a route, packets are forwarded to RSU so the receiver is closer to the RSU than the sender. Hence, vehicles with link quality "00" can only receive sender's link quality "00" and vehicles with link quality "01" or "10" cannot receive sender's link quality "11". If a vehicle receives a packet sent from a sender, the receiver will do the following actions according to its current link quality. In case (1), assuming the link quality of the receiver to the nearest RSU is "00", it implies that the link quality of sender to the RSU is "00" too. Thus, the receiver will send the received packet to its next-hop neighbor.

In case (2), assuming the link quality of the receiver to the nearest RSU is "01", it implies that the link quality of the sender is "00" or "01". Since the link quality of receiver is "01", the RSU may receive packet from the receiver directly. If the link quality of sender is "00", the receiver will send the packet to its next-hop neighbor. If the RSU can receive the sending packet, it will reply a message to the receiver. In the next packets forwarding, the receiver will forward the packets to the RSU directly and change its next-hop neighbor to the RSU. If the link quality of sender is "01", it means that the sender may send packet to the RSU directly. The receiver just listens whether there is a reply message sent from the RSU. The receiver will wait a *time_slot* interval to listen the channel. If the receiver overhears a reply from the RSU, the receiver will drop the packet sent from the sender. Note that, if the sender can receive a reply from RSU, it will change its next hop to the RSU. Otherwise, the receiver will forward the packet to its next-hop neighbor. For example, in Fig. 5, sender sends packet with its link quality to receiver. If RSU receives the packet, it will send a reply to the sender. At the same time, receiver overhears the reply from RSU and it drops the packet sent from sender. In the next transmission, sender will send packets to RSU directly. In Fig. 6, if RSU does not receive the sending packet, it will not send a reply to sender. As receiver does not overhear a reply from RSU, it forwards the packet to RSU.

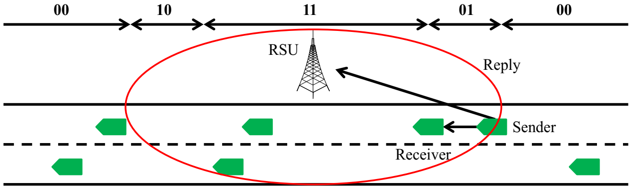

Figure 5. Sender sends packets to RSU and receiver drops the packets when RSU sends a reply.

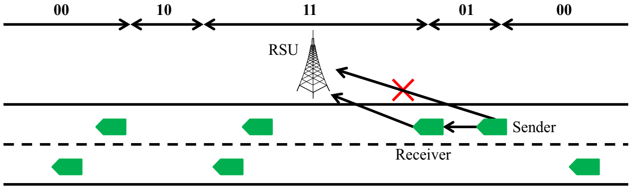

Figure 6. Receiver sends packets to RSU when RSU does not send a reply.

In case (3), assuming the link quality of the receiver to the nearest RSU is “10”, it implies that the link quality of the sender is “00” or “10”. Since the link quality of receiver is “10”, the RSU may receive packet from the receiver directly, but the receiver is moving away from the RSU. In order to extend the connection time to the RSU, the receiver has to search a backward vehicle to transmit packets to the RSU. If the link quality of sender is “00”, the receiver sends packet to the RSU and it will also broadcast a routing request to its neighbor vehicles. A vehicle with farther distance from the receiver and link quality is “11” will send a reply to the receiver. The vehicle which sends a reply is called the backward vehicle will set its next-hop neighbor to the RSU. In the next packets forwarding, the receiver will forward the packet to the backward vehicle and change its next-hop neighbor to the backward vehicle. If the link quality of sender is “10”, it means that the sender may send packet to the RSU. The receiver just waits a *time_slot* period to listen whether there is a reply message from the RSU. If the receiver overhears a reply from the RSU, the receiver will drop the packet sent from the sender. Otherwise, the receiver will forward the packet to its next-hop neighbor and broadcast a routing request to find a backward vehicle. In Fig. 7, receiver sends packet to RSU and then broadcasts a routing request to its neighbors. The backward vehicle sends a reply to the receiver. In the next packets transmission, receiver sends packets to the backward vehicle and then the backward vehicle sends packets to RSU.

In case (4), assuming the link quality of the receiver to the nearest RSU is “11”, it implies that the link quality of the sender is “00”, “01”, “10”, or “11”. Since the link quality of receiver is “11”, the receiver can send packet to RSU directly. If the link quality of sender is “00”, the receiver will send the packet to the RSU. If the link quality of sender is “01”, “10”, or “11”, it means that the RSU may receive packet from the sender. The receiver just listens whether there is a reply message sent from the RSU. If the receiver overhears a reply from the RSU, the receiver will drop the packet sent from the sender. Otherwise, the receiver will forward the packet to the RSU. In Fig. 8, Sender can send packets to RSU. Receiver receives the packet sent from sender and then it overhears a reply from RSU; Receiver drops the packet sent from Sender.

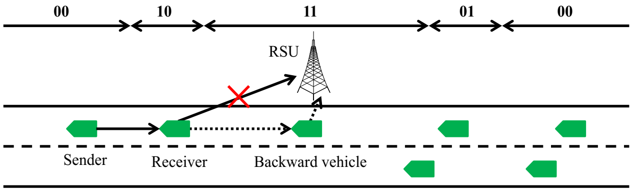

Figure 7. The routing path is changed from receiver→RSU to receiver→backward vehicle→RSU.

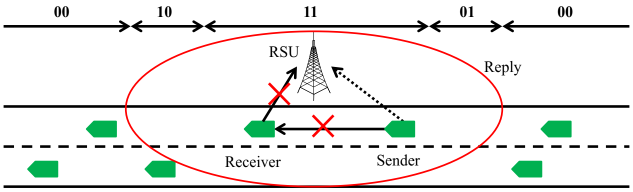

Figure 8. The routing path is changed from sender→receiver→RSU to sender→RSU.

In the following, we consider the inter-RSUs handover. When a source vehicle gradually keeps increasing its distance from the connected RSU, the hop-count will increase from the source to the RSU which might cause low bandwidth and high delays. A source vehicle will initiate an inter-RSUs handover when the source finds a new RSU which has a shorter routing distance than that to the original RSU in the digital map. The handover request is similar to forwarding requests mechanism. The source vehicle broadcasts a handover request to its neighbor vehicles. If a receiver is the closest to the new RSU than other vehicles, it will rebroadcast the handover request. Vehicles continue the above steps until the new RSU receives the handover request. After receiving the handover request, the new RSU sends a reply to the source vehicle and changes its next-hop neighbor to the destination’s RSU. If the hop-count of the new route is smaller than the original route, the source vehicle chooses the new route to send packets to the destination vehicle. Otherwise, the source vehicle keeps sending packets via the original route. Either the source or destination vehicle can initiate the inter-RSUs handover request. Fig. 9 shows an example of an inter-RSUs handover, where source claims an inter-RSUs handover request to the nearest RSU_2. Source compares the hop-count of the route to RSU_1 with the hop-count of the route to RSU_2. Source chooses the new route to RSU_2 with less hop-count and discards the original route to RSU_1; the RSU_2 changes its next RSU to RSU_3. The pseudo codes of routing and handover schemes are listed in Algorithm 3.1 and Algorithm 3.2.

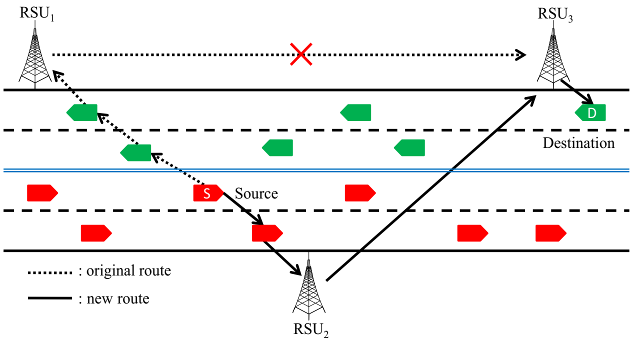

Figure 9. Source transmits packet to destination via the new route.

Algorithm 3.1: Routing protocol

```
/* Registration */
If a vehicle receives the advertisement of a RSU then the
vehicle registers with the RSU and the RSU sends the
vehicle's current location to its home RSU.
/* Forwarding Requests */
If a vehicle receives a new routing request and TTL <
threshold then the vehicle set TTL=TTL+1 and select a
back-off time according to equation (1) to rebroadcast the
routing request.
If a RSU receives a new routing request then the RSU
sends the routing request through the backbone to the
```

```
    home RSU of destination.
If the home RSU receives a routing request then the home RSU sends the routing request to the registered RSU of destination.
If the registered RSU receives a routing request then the RSU performs a local flooding to search the destination vehicle.
If a destination receives a routing request then the destination sends a reply to the source through the reverse path.
If a vehicle receives a data packet then Handover().
```

Algorithm 3.2: Handover

/* If a vehicle *A* receives a data packet from a sender *B*, the vehicle *A* will check the following cases. */

```
case 1: my link quality is "00"
    Vehicle A sends data packet to its next-hop neighbor.
case 2: my link quality is "01"
    If sender's link quality is "00" then vehicle A sends data packet to its next-hop neighbor.
    If vehicle A can receive reply from RSU directly then vehicle A changes its next-hop neighbor to the RSU.
    If sender's link quality is "01" and vehicle A overhears a reply from RSU to sender B then vehicle A drops the data packet else vehicle A sends the data packet to its next-hop neighbor.
case 3: my link quality is "10"
    If sender's link quality is "00" then vehicle A sends data packet to RSU and finds a backward vehicle to replace the sender B.
    If sender's link quality is "10" and vehicle A overhears a reply from RSU to sender B then vehicle A drops the data packet else vehicle A sends data packet to its next-hop neighbor.
case 4: my link quality is "11"
    If vehicle A overhears a reply from RSU to sender B then vehicle A drops the data packet else sends the data packet to RSU.
```

In summary, there are three time costs in our proposed scheme, including the time of a source vehicle sending routing request to a nearest RSU, the time of the nearest RSU forwarding routing requests to the destination's home RSU and then the home RSU forwarding routing request to the destination's registered RSU, and the time of the registered RSU using local flooding to find the destination vehicle.

IV. SIMULATIONS

In this section, we evaluate the performance of our protocol through simulations. The first simulation scenario is in a highway and the second scenario is in a city. We use the VanetMobiSim [17] traffic simulator to generate the movements of the vehicle nodes. Then, the performance metrics that are used to evaluate the simulation results are packet delivery ratio, control overhead, route lifetime, handover times, and handover delay in the network simulator ns-2.

In our experiments, the highway is an 8000 meters long straight road. The number of RSUs is five and the RSUs are evenly distributed along the roadside every 2000 meters. The highway allows two-way movement of vehicles and we have two lanes in each direction; the wide between each lane is 5 meters. The vehicles are randomly distributed in each lane and a vehicle turns back when it reaches the border of the simulation area. The average speed of vehicles is between 80-100 km/hr. We test our protocol with three vehicle densities: low (5 vehicles/km), medium (10 vehicles/km), and high (20 vehicles/km). We discard the first 600 seconds of the VanetMobiSim output to obtain more accurate node movements. The output from VanetMobiSim is converted into input file for the movement of nodes in the ns-2 simulator.

For the wireless configuration, we use the IEEE 802.11 with DCF standard at the MAC layer in ns-2. At the physical layer, we used the two-ray ground propagation to characterize physical propagation. The communication range of vehicles and RSUs is 250 meters. RSUs generate one advertisement per 10 seconds. We randomly select source vehicle and destination vehicle from the input vehicles. When a routing request cannot be successfully established, the source will re-initiate a routing request after time-out (10 seconds). For each transmission, connections are established to use constant-bit-rate (CBR) traffic at 10 packets/seconds with a message of size 512 bytes. The simulation time is set 3000 seconds and we observe the output data every 60 seconds.

The packet delivery ratio is the fraction of originated data packets that are successfully delivered to destination vehicles. In Fig. 10, we compare the packet delivery ratio in our protocol and RAR under different number of vehicles. We can see that the packet delivery ratio decreases as number of packets increases in our protocol and RAR. When source needs to send more packets to destination successfully, the connection time between each vehicle needs be longer. Packet delivery ratio in high vehicle density is higher than medium and low vehicle densities. This is because source is easy to find relay vehicles to forward packets to destination in the VANETs. Our protocol achieves higher packet delivery ratio than RAR. This is because we consider the handover schemes from a source to destination vehicle. The RAR arbitrarily selects a relay vehicle to forward packets in its neighbor vehicles that will increase packets collision.

The routing overhead is the ratio of the control packets over the total numbers of transmission packets. The control packets are forwarded by intermediate vehicles to discover

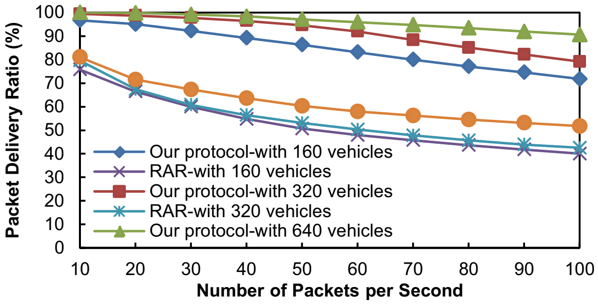

Figure 10. Packet delivery ratio versus number of packets in highway.

the route from source to destination vehicles. The control packets are also included the periodical advertisements from RSUs and vehicles send packets to register with RSUs. In Fig. 11, we evaluate the routing overhead of the two protocols as a function of the number of vehicles. It is observed that the routing overhead stays approximately constant for the two routing protocols. In our protocol, routing requests go through the nearest RSU of the source, the home RSU of the destination, and the registered RSU of the destination, so the cost is constant. In RAR, routing requests go through the RSU which receives request first and visit all RSUs to find the destination's sector. Finally, the two RSUs which enclose the sector will forward routing requests to the destination, and thus RAR's overhead is higher than our protocol. Additionally, we discard periodical advertisements from RSUs in both our protocol and RAR. It is observed that the difference between protocols with and without periodical advertisements is small in both routing protocols.

The route lifetime is the connection time between a source and destination vehicle. As shown in Fig. 12, we can see that the increase in the number of vehicles leads to an increase in the route lifetime. This is because more vehicles in the VANETs provide a good opportunity to select an appropriate relay vehicle which in the same moving direction with the sender. Route lifetime in our protocol is longer than RAR. This is due to vehicles drive through RSUs can handover with other vehicles to prolong the access time to RSUs in our protocol but RAR did not consider handoff to increase the link lifetime between vehicles and RSUs.

In a city environment, the experiment is a 2000 meters × 2000 meters square street area, which presents a grid layout of city roads. RSUs are distributed at the major intersections every 1000 meters. We set five vertical and five horizontal two-way roads in the environment. The vehicles are randomly deployed to the map and the average speed of vehicles is chosen between 40-60 km/hr. Traffic lights change every 60 seconds. RSUs generate one advertisement per 20 seconds. Other simulation parameters are the same with the highway environment.

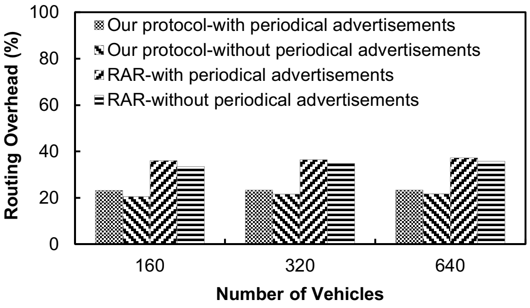

Figure 11. Routing overhead versus number of vehicles in highway

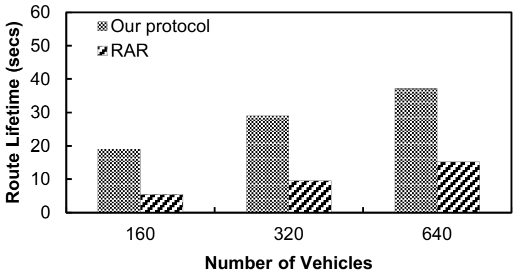

Figure 12. Route lifetime versus number of vehicles in highway

In Fig. 13, we compare the packet delivery ratio in our protocol and RAR under different number of vehicles. We can see that the difference of packet delivery ratio is small with different number of vehicles. This is because the speed of vehicles is affected by traffic lights and the road was congested with cars. The packet delivery ratio in our protocol is higher than RAR in various vehicle densities.

Fig. 14 shows that the routing overhead in our protocol and RAR under different number of vehicles. Two routing protocols stay approximately constant for the different number of vehicles. This is because there are constant steps sending routing requests from a source to destination vehicle. The overhead in our protocol is lower than RAR. The reason is same as described in the highway environment.

In Fig. 15, we can see that the increase in the number of vehicles leads to an increase in the route lifetime. This is because more vehicles in the VANETs provide a good opportunity to select a relay vehicle to forward packets. Route lifetime in our protocol is longer than RAR. This is due to vehicles drive through RSUs can handover with other vehicles to prolong the access time to RSUs in our protocol but RAR did not consider handoff to increase the link lifetime between vehicles and RSUs.

Fig. 16 shows the handover times for inter-RSUs and intra-RSU handovers in our protocol with various number of vehicles. The handover times for inter-RSUs are the times a source or a destination vehicle changes its original RSU to a new RSU. The handover occurs when vehicles move away more than 500 meters from its connected RSU. The average handover period for inter-RSUs handover is two minutes.

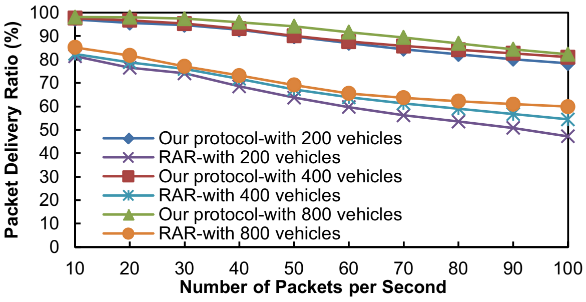

Figure 13. Packet delivery ratio versus number of packets in city

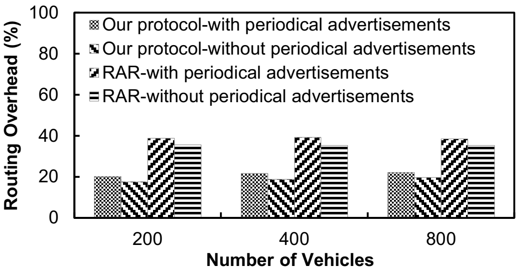

Figure 14. Routing overhead versus number of vehicles in city.

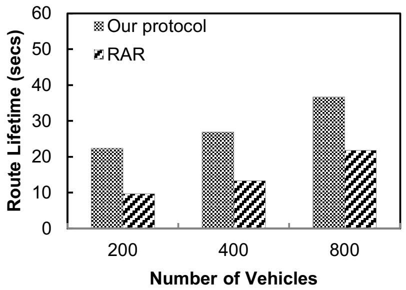

Figure 15. Route lifetime versus number of vehicles in city.

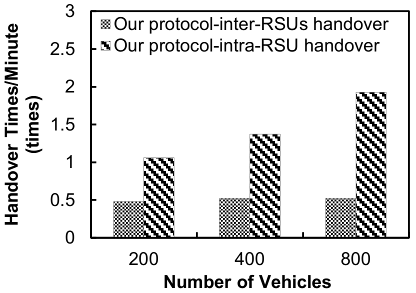

Figure 16. Handover times in a minute versus number of vehicles in city.

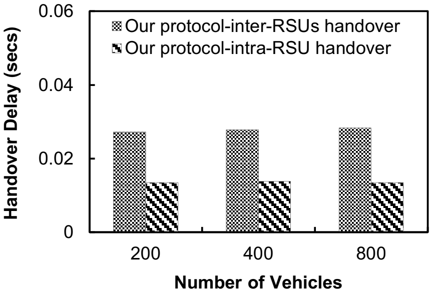

Figure 17. Handover delay versus number of vehicles in city.

On the other hand, the handover times for intra- RSU are a vehicle changes its next-hop neighbor from a vehicle to a RSU or from a RSU to a vehicle. The frequency of intra-RSU handover is larger than inter-RSUs handover. In addition, lower number of vehicles has lower handover times for intra-RSU handover. This is because handover occurs when vehicles have their link qualities as "01" or "10".

The handover delay for inter-RSUs is the interval that a source or destination vehicle successfully constructs a route to a new RSU. In Fig. 17, as the number of vehicles increases, the delay of inter-RSUs handover stays constant since the hop-count from a source (destination) to a new RSU is only 2-3 hops. Fig. 17 also shows that the handover delay of intra-RSU handover is smaller than inter-RSUs. This is because the intra-RSU handover only occur within a RSU's transmission range.

V. CONCLUSION

Our protocol efficiently utilizes the distributed characteristic of vehicular environments to change routes from source vehicles to destination vehicles in hybrid VANETs. With the aid of RSUs, the location service provides fewer routing requests to search for the destination vehicles. We propose two distributed handover schemes between vehicles and RSUs. The handover schemes achieve good performance such as high packet delivery ratio and long route lifetime. Our protocol is concentrated on physical-world traffic rules such as road layouts and vehicle densities have a significant impact on the networking performance. The simulation results show that our protocol outperforms existing approaches in terms of packet delivery ratio, control overhead and route lifetime.

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