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***Abstract*—Routing is a critical issue in vehicular ad hoc networks (VANETs). This paper considers the routing issue in both vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications in VANETs, and proposes a Moving dirEction and DestinAtion Location based routing (MEDAL) algorithm for supporting V2V and V2I communications. MEDAL takes advantage of both the moving directions of vehicles and the destination location to select a neighbor vehicle as the next hop for forwarding data. Unlike most existing routing algorithms, it only uses a HELLO message to obtain or update routing information without using other control messages, which largely reduces the number of control messages used in routing. Simulation results show that MEDAL can significantly improve the packet delivery ratio of the network as compared with the well-known Ad hoc On-demand Distance Vector Routing (AODV) algorithm.**

Keywords—destination location; moving direction; routing; VANET

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) are an emerging networking technology for supporting intelligent transportation systems (ITS) [1]. In a VANET, communication occurs from vehicle to vehicle (V2V) or from vehicle to infrastructure (V2I). A vehicle needs to transmit its data to other vehicles or roadside units to provide a variety of applications, such as traffic control, environment monitoring, and inter-vehicle communication. For this purpose, a path needs to be established between a source and its destination or roadside unit before data transmission, and routing therefore becomes a critical issue in the design of a VANET.

A VANET is a special type of mobile ad hoc networks (MANETs). It has some characteristics similar to those of MANETs, such as self-organization, self-management and short-range radio transmission. In addition to these similar characteristics, a VANET also has some unique characteristics, such as highly dynamic topology, sufficient energy capacity, and predictable mobility model. In particular, the moving speed of a vehicle can usually reach 70km/h in a street scenario or even 120km/h in a highway scenario. If two cars at a distance of 250m are moving in the opposite directions at a speed of 25m/sec (90km/h), the communication link can last for only 10 seconds. This would result in a highly dynamic topology of the network, which presents a big challenge in the design of a routing protocol.

To address the unique characteristics of VANETs, a variety of routing protocols have recently been proposed for different network scenarios, such as AODV (Ad-hoc On-demand Distance Vector) [2] and DSR (Dynamic Source Routing) [3], which were originally proposed for MANETs but can also be used for VANETs with lower throughput [4]. Moreover, GPSR (Greedy Perimeter Stateless Routing) [5] is a well-known routing protocol proposed particularly for VANETs, which can achieve a better performance than AODV and DSR in a suburban scenario. GPCR (Greedy Perimeter Coordinator Routing) [6] is another routing protocol proposed particularly for VANETs, which is based on GPSR and does not use any street map. Although these routing protocols have been proposed for VANETs, all of them have this or that limitation in achieving network performance or addressing different network scenarios. Therefore, more efficient routing protocols are still expected to achieve better performance in different scenarios of a VANET.

In this paper, we consider the routing issue in both V2V and V2I communications in a VANET, and propose a Moving dirEction and DestinAtion Location based routing (MEDAL) algorithm for supporting V2V and V2I communications. MEDAL makes use of both the moving directions of neighbor vehicles and the destination location to make a routing decision or select the next hop for forwarding data. In the case of no neighbor vehicles, a node employs a store-carry-forward mechanism to store and carry its data packets until it meets an appropriate neighbor node for forwarding the packets. On the other hand, the routing information maintained at each node may quickly become ineffective within a few minutes in a VANET because of the high moving speed of a vehicle. For this reason, more control messages need to be exchanged between different nodes to timely obtain or update the routing information maintained at each node. This would reduce the

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resource utilization and is thus not desirable. To address this problem, MEDAL only uses a HELLO message to obtain or update routing information without using other control messages, e.g., REQUEST and REPLY messages. Simulation results show that MEDAL can significantly improve the packet delivery ratio of the network as compared with the Ad hoc On-demand Distance Vector Routing (AODV) algorithm.

The remainder of this paper is organized as follows. Section II reviews related work on routing protocols for VANETs. Section II presents the proposed MEDAL algorithm. Section IV shows simulation results to evaluate the performance of MEDAL. Section V concludes this paper.

II. Related Work

Routing has been widely studied for VANETs. A variety of routing algorithms have been proposed in the literature, which can be classified into five categories: ad hoc routing, position-based routing, cluster-based routing, broadcasting, and geocast routing [7]. Among all these routing categories, position-based routing and geocast routing have widely been considered as a promising routing paradigm for VANETs.

AODV [2] is a well-known routing algorithm originally proposed for MANETs. Although it can also be used for VANETs, it cannot achieve good throughput performance because of the high mobility of vehicles. In [8], Lochert et al. proposed PRAODV, which is based on AODV and uses the notion of the link and route time estimates. Moreover, it constructs a new alternate route before the end of the estimated lifetime, which is predicted based on the speed and location information. Cluster-based routing is particularly suitable for a network with a large number of vehicles. It clusters the vehicles in the network into a virtual network structure to provide better scalability. In [9], Choffnes and Bustamante proposed a clustering algorithm called COIN (Clustering for Open IVC Networks), which selects a cluster head based on vehicular dynamics and drivers' intentions while other clustering algorithms select a cluster head based on vehicles' IDs or mobility. However, clustering leads to more delay and overhead in routing, which may not be suitable for a network with a highly dynamic topology. Broadcasting is the simplest routing way widely used for VANETs. However, it causes contentions and collisions, which would affect network performance. Geocast routing is a special type of multicasting. In [10], Briesemeister proposed a geocast routing algorithm, which rebroadcasts the received packets after a waiting time to avoid contentions and collisions.

In the context of position-based routing protocols, Lee et al. proposed TO-GO (Topology-assist Geo-opportunistic Routing) in [11], which makes use of the topology knowledge and 2-hop beaconing to select the best forwarder and also uses opportunistic packet reception to increase the packet delivery ratio. In [5], Karp and Kung proposed GPSR, which combines greedy routing and facing routing, where facing routing is used to get out of a local minimum when greedy routing is impossible. GPSR is very suitable for V2V communications in a highway scenario, but not in an urban scenario because direct communication between vehicles may not be possible and thus greedy routing may not succeed. In this case, packets need to travel along a long path to reach the destination and most of them may be dropped during the routing process. In [6], Lochert et al. proposed GPCR, which does not use any global information for routing and is based on the assumption that the streets and junctions form a natural planar graph. Similar to GPSR, GPCR also consists of two components: a greedy routing algorithm and a repair strategy. Compared with GPSR, the greedy routing is restricted to a certain area in the network and data packets are always routed along the streets. Moreover, it assumes that there is always a node at any junction and a routing decision is only made by the node at a junction. In this case, a packet must always be forwarded to the node at a junction rather than forwarded directly to a node across a junction. In the repair strategy, a well-known right-hand rule [5] is applied to recover from the local minimum. In the real world, however, the assumption that there is always a node at a junction is not reasonable, which limits the use of GPCR. To address this problem, we present MEDAL which does not need a junction node and allows a node to directly make a routing decision or forward data packets in a pre-intersection area.

III. Destination Location Based Routing Protocol

In this section, we present MEDAL: a novel position-based routing protocol for VANETs.

A. Network Model

We consider an urban grid network, in which the streets are distributed only horizontally and vertically, as shown in Figure 1.

In this network model, all the streets have two lanes and are segmented by traffic lights, whose cycle time is set to a constant. Two vehicles can communicate with each other when they are located within the communication range or radio transmission distance of each other.

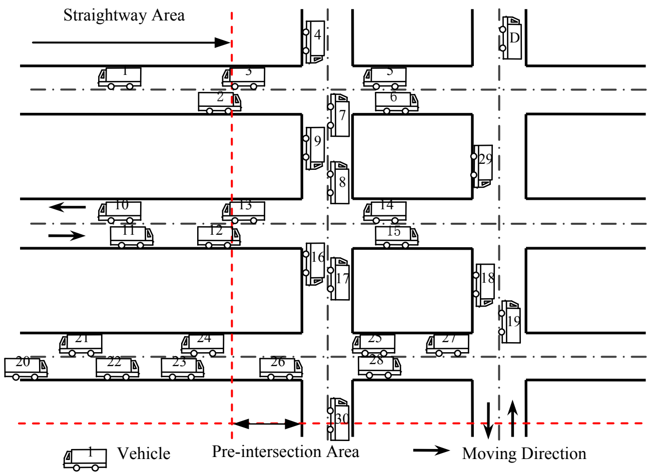

Figure 1. An example of the network model

In this network model, we assume that a vehicle is equipped with a Global Positioning System (GPS) device and a digital map, which provides the position of the vehicle itself and the location of the destination. All the vehicles have no limit on energy and buffer capacity. Because of the obstacles between two parallel streets and the distance between them, which is usually much larger than a vehicle's transmission range, two vehicles between two parallel streets cannot communicate with each other. The destination of a data packet can be a stationary road-side unit (RSU), or a moving vehicle whose real-time position can be obtained by other vehicles through the equipped digital devices. Moreover, we do not consider the car overtaking behavior in this work.

B. Routing Strategy

The main idea of MEDAL is to take advantage of the moving directions of vehicles and the destination location to select a neighbor vehicle as the next hop for forwarding data.

In MEDAL, each vehicle periodically broadcasts a HELLO message, which contains the vehicle's ID, position, driving direction, and moving speed, to discover its one-hop neighbors. After a vehicle receives the HEELO message, it stores all the information contained in the message and adds the sender's information to its neighbor table. In addition to the neighbor table, each vehicle also maintains a data list locally. When a vehicle receives a data packet, it first checks the packet's ID in its data list. If the packet already exists in the list, the vehicle will drop the packet. Otherwise, the packet will be added into the list in a first-in-first-out manner.

C. Protocol Description

MEDAL consists of two procedures: a straightway procedure and a pre-intersection procedure. When a source node generates or an intermediate node receives a data packet, it will first store the packet and then trigger a routing procedure. If the node is located at a position with a distance prior to an intersection, which is based on the transmission range of a vehicle and the width of a street, the pre-intersection procedure is triggered. Otherwise, the straightway procedure is triggered. The above process is repeated until the packet arrives at the destination or the Time To Live (TTL) in the packet reaches zero. The procedures of the MEDAL algorithm are described in Figure 2.

MEDAL Algorithm

```
Let     ID ← vehicle's ID;
        destination ← packet's destination;
        position ← vehicle's position;
        0 ← pre-intersection;
Initialization: ID receives or generates a packet
    if TTL ≠ 0 & ID ≠ destination then {
        update position;
        if position = 0 then
            {trigger the pre-intersection procedure;
                return; }
        else
            { trigger the straightway procedure;
                return; }
    } else {
        store the packet;
        return;
    }
```

Figure 2. Routing procedured of MEDAL

a) Straightway Procedure

The straightway procedure is similar to a traditional greedy routing algorithm. In this procedure, if a vehicle has no neighbor, it will store and carry the packet in its data list until it meets another vehicle. Compared with the conventional greedy routing, the difference is that the straightway procedure first compares a packet's destination location with the driving direction and chooses the vehicles whose driving directions are towards the destination as the candidate next hops. Then, if the destination is in the neighbor table of the current vehicle, the data packet is forwarded to the destination directly. Otherwise, the vehicle with the shortest distance to the destination will be selected as the next hop. If the current vehicle itself has the shortest distance to the destination, it will continue to carry the packet until it meets a neighbor vehicle closer to the destination.

Figure 1 illustrates an example of the straightway procedure, in which vehicle 20 is driving on a straight way. If the vehicle receives or generates a packet for vehicle D, it triggers the straightway procedure. In this case, its neighbors include vehicles 21, 22, 23 and 24, among which vehicle 24 is the closest to the destination D. However, the moving direction of vehicle 24 is in the opposite direction of the destination. As a result, vehicle 23 is selected as the next hop.

b) Pre-Intersection Procedure

In [6], GPCR assumes that there is always a node at a junction and a routing decision is only made by the node at a junction. But in the real world, this assumption is not reasonable because it is impossible to always have a forwarding node at a junction. To address this problem, MEDAL allows a node in a pre-intersection area to make a routing direction without using a junction node. The definition of a pre-intersection area is based on the distance between a vehicle and an intersection, the transmission range of the vehicle and the width of a street. Figure 1 shows an example of a pre-intersection area. If a vehicle is far away from the destination, the width of a street can be ignored.

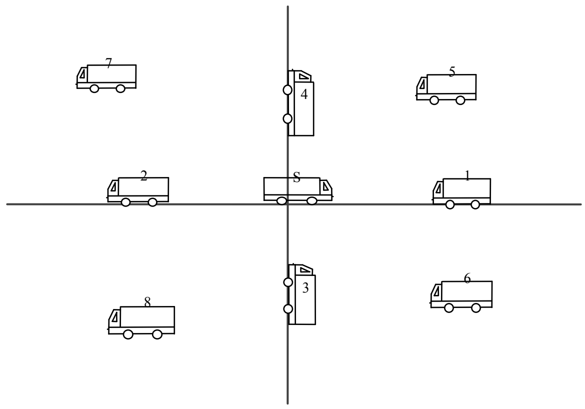

Figure 3. Eight cases of the relative position

Similar to the straightway procedure, the pre-intersection procedure first determines the neighbors of a vehicle and then selects the more appropriate one as the next hop. According to the position of a vehicle and the destination location, the relative position of the destination respect to the vehicle may have eight cases: east, west, south, north, northeast, southeast, northwest and southwest, as shown in Figure 3. If the relative position belongs to the former four cases, the selected neighbor vehicles can only move in one direction, denoted by dir_. Otherwise, the vehicles can move in two directions, denoted by dir1_ and dir2_. For example, if the relative position is southwest, dir1_ is south and dir2_ is west. If the relative position is south, dir_ is south. The pre-intersection procedure can be described as follows:

- Step1: A vehicle with a packet to transmit checks its neighbor list periodically. If the vehicle does not have neighbors, it carries the packet until it meets a neighbor vehicle. Otherwise, turn to step 2;
- Step 2: Based on the vehicle's position and the destination's location, the vehicle calculates the relative position of the destination respect to the vehicle itself. If the relative position is in the vertical or horizontal direction, turn to step 3. Otherwise, turn to step 4;
- Step 3: Choose the neighbor vehicles whose driving directions are the same as dir_. From these neighbor vehicles, select the one with the shortest distance to the destination as the next hop and forward the packet to it. Otherwise, turn to step 1;
- Step 4: If some neighbors' driving directions match dir1_ or dir2_, turn to step 5; Otherwise, if there are some neighbors driving in dir1_ and some driving in dir2_, turn to step 6; otherwise, turn to step 1;
- Step 5: Select the neighbor with the shortest distance to the destination as next hop. Then, forward the packet to it.
- Step 6: The neighbors of the vehicle are usually moving on different streets with different speed limits. According to the car-following theory [12], if a vehicle drives at a much lower speed than the road speed limit, it is likely that there are some vehicles in front of it. Therefore, compare the neighbor vehicles' speeds with the roads' speed limits, select the vehicle with the maximum speed difference as the next hop, and then forward the packet to it.

Figure 1 also gives some examples to illustrate the pre-intersection procedure. For example, if vehicle 2 is a source node and the destination of a packet is vehicle D. The candidate neighbors are vehicles 3, 4, 5, 6, 7 and 9, and the next hop can be selected according to step 2. Vehicle D is in the northeast of vehicle 30, whose neighbors are vehicles 25, 26 and 28, moving in the east or west direction, and dir1_ and dir2_ are set to north and east, respectively. By step 5, the next hop can be selected. Vehicle 12 is the most complicated case, and just like vehicle 30, dir1_ and dir2_ are north and east. The candidate neighbors include vehicles 8, 13, 14, 15, 16 and 17, which are distributed on different streets with different speed limits. In this case, step 6 is used to select the next hop.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the MEDAL algorithm through simulation results. For evaluation, we compare MEDAL with AODV in terms of packet delivery ratio and latency. The simulation experiments were conducted on NS2.35 [13] and IEEE 802.11 with a transmission rate of 2Mbps and a transmission range of 250m was used as the underlying MAC protocol. We used VanetMobiSim [14] to generate a 4 x 4 urban grid topology of a 1600m by 1600m area. All streets have two lanes and are bi-directional. All intersections are controlled by traffic lights and all street segments have speed limits. In VanetMobiSim, the micro-mobility is controlled by the IDM-IM, an extension to the Intelligent Driver Model (IDM) considering intersections. In each simulation run, we randomly selected five sender-receiver pairs, using 512-byte constant bit rate (CBR), an UDP-based packet generation application. In the simulations, the number of vehicles considered is 20 to 40. The running time of each run is 500 to 1000 seconds. All simulation results are an average over 10 runs. Table 1 summarizes the parameters used in the simulations.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Network simulator	NS2
Mobility simulator	VanetMobiSim
Simulation area	1600m x 1600m
CBR rate	512bytes/second
802.11 rate	2Mbps
Transmission range	250m
Simulation runs	10
Average vehicle speed	50km/hr
Simulation time	500 to 1000 sec
Number of vehicles	20 to 40

Figure 4 shows a snapshot of the network topology with 30 vehicles, where vehicle 2 has a packet whose destination is vehicle 12.

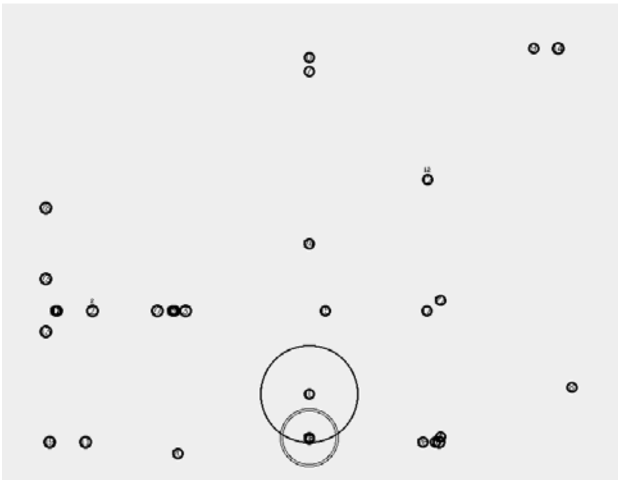

Figure 4. A snapshot of the network topology

Figure 5 and Figure 6 show the average packet delay and the packet delivery ratio with the AODV algorithm and the MEDAL algorithm, respectively, under different simulation time. It is seen that the packet delivery ratio with MEDAL is larger than that with AODV, which is expected. However, the average packet delay with MEDAL is also increased as compared with AODV. This is because MEDAL is proposed for delay-tolerant applications. It employs the store-and-carry strategy in routing when a vehicle does not have an appropriate neighbor vehicle to forward its packets.

Figure 7 shows the packet delivery ratio with the AODV algorithm and the MEDAL algorithm, respectively, under different node densities. It is seen that the packet delivery ratio increases with the node density increasing. The MEDAL algorithm can significantly improve the packet delivery ratio as compared with the AODV algorithm.

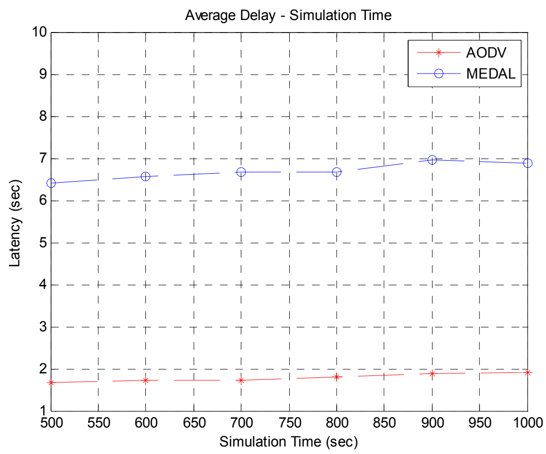

Figure 5. Average packet delay vs simulation time

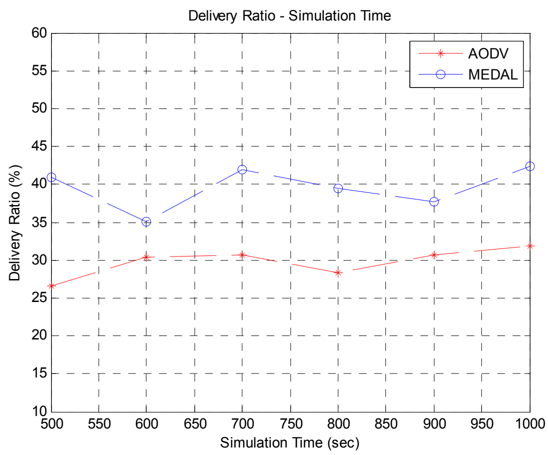

Figure 6. Delivery ratio vs simulation time

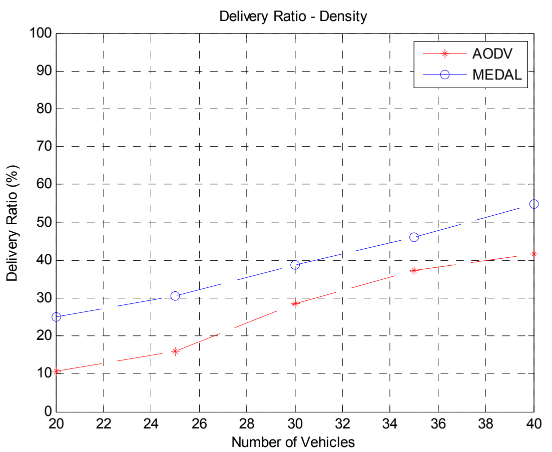

Figure 7. Delivery ratio vs node density

V. Conclusions

In this paper, we proposed a Moving dirEction and DestinAtion Location based routing (MEDAL) algorithm for data transmission in an urban scenario of VANETs. MEDAL makes use of both the moving directions of vehicles and the destination location to select the next-hop vehicle for forwarding data, and allows a node to make a routing decision and forward data packets in a pre-intersection area. Moreover, it only uses a HELLO message for obtaining or updating routing information, which largely reduces the number of control messages used in routing. The simulation results have shown that MEDAL can significantly improve the packet delivery ratio with a slightly increased average packet delay. Since MEDAL is proposed for delay-tolerant applications, the packet delivery ratio is more concerned than the packet delay in performance evaluation. In future work, we will consider the extension of MEDAL to a more practical scenario.

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