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Efficient Data Dissemination Scheme for the Urban Vehicular *ad hoc* Networks

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Abstract: Due to the rapid network topology change of vehicular *ad hoc* networks (VANETs), the implementation of reliable data dissemination among vehicles has encountered many challenges. In this study, the Hierarchical Assisted-node-based Data Dissemination Scheme (HADD) of VANETs is presented. Since the vehicle mobility is limited to the road layout, the relative locations among vehicles are partially predictable. In our scheme, the location predictability among neighbor vehicles is taken into consideration to reduce the communication failure caused by the rapid change of the relative locations. Considering the drivers' requirement degree for the data source information varies with different distances, the amount of data is customized according to the different requirements in order to reduce the channel conflict and increase the data dissemination efficiency. Simulation results show that the novel scheme can obviously improve the network performance of data dissemination rate and delay.

Key words: Reliable, efficient, data dissemination, vehicular *ad hoc* networks

INTRODUCTION

Vehicular *ad hoc* Networks (VANETs) are vehicle centric large-scale communication networks. By equipping vehicles with on-board wireless communication facilities, communications among vehicles in proximity can be enabled (Misener, 2005). With VANET, a variety of applications relating to the safety (e.g., collision detection and lane changing warning) and infotainment can be provided to drivers and passengers on the road (Bai and Krishnamachari, 2010; Luan *et al*., 2011). This not only makes the transportation system safer and more efficient but also revolutionizes users' in-vehicle experience (Yang *et al*., 2004).

Among all the applications of the VANET, data dissemination is considered to be the fundamental technology. And the efficient, reliable and real-time data dissemination mechanism is of great importance to ensure the correct operation of various kinds of applications. However, the rapidly link topology change among vehicles (or nodes) may bring researchers many design challenges (Mak *et al*., 2005) and many efficient data dissemination mechanisms for mobile *ad hoc* networks are not suitable for VANETs (Namboodiri *et al*., 2004; Wu *et al*., 2004; Naumov *et al*., 2006).

Extensive research efforts have been made to investigate the key issues of data dissemination in VANETs. The flooding-based schemes can be implemented in a simple way and mitigate the impact of the transmission instability on the network performance even in rapidly mobile environment (Tokuda *et al*., 2000; Biswas *et al*., 2006). However, since all the vehicles in the network are expected to broadcast data packets, it may lead to serious communication channel conflict, especially when the vehicle density is very high and there are much more data packets to be broadcasted. This issue could significantly lower the data dissemination rate and increase the network delivery delay because of the broadcast storm (Ni *et al*., 1999).

The authors (Sun *et al*.,2000; Korkmaz *et al*., 2004; Massashi *et al*., 2004; Alshaer and Horlait, 2005) present the neighbor-based data dissemination scheme to select one or several vehicles as forwarders to broadcast data at a time to decrease the redundant network traffic. Each vehicle in the network conducts and updates a list of neighbor vehicles. Compared with the flooding scheme, this scheme provides better performance in terms of network traffic and delivery delay. However, while the transmitting process is unfinished, the selected forwarder may run out of the communication range of the sending forwarder because of the vehicle's random movement. Thus this scheme is not efficient for a network with the rapidly topology changing and would cause delivery delay and data packet loss greatly.

The cluster-based broadcast scheme shows good performance when the network topology changes slowly

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(Santos *et al*., 2004; Durresi *et al*., 2005). It divides vehicles into several clusters and selects a cluster head among vehicles within a cluster. Only the cluster head is eligible to broadcast data. Since it is required to reorganize the cluster members and select a cluster head more frequently, this scheme suffers from heavy network traffic and long delay when the network topology changes fast.

Therefore, there are two issues that the efficient data dissemination mechanism aims to solve. The first issue is to lower the impact on the communication stability due to the rapidly network topology change among vehicles and the other is to lower the impact on the communication quality due to the broadcast storm in high-density VANETs.

In this study, a novel data dissemination scheme based on assisted nodes, i.e., the hierarchical Assisted-node-based Data Dissemination Scheme (HADD), is presented. Since the vehicle mobility is limited to the road layout, the relative locations among vehicles are partially predictable. In our scheme, the relative location is taken into consideration to reduce the communication failure caused by the rapid change of the relative locations. Moreover, the assisted nodes deployed at the intersection have been considered to increase the network data dissemination efficiency. It is observed that the drivers' requirement degree for the data source information varies with different distances. The longer the distance between the data source and the vehicle, the lower the vehicle's requirement degree for the data source information. In our scheme, before the data is transmitted by the assisted node, the amount of data is customized according to the different requirements in order to reduce the channel conflict and increase the data dissemination efficiency. Simulation results show that our novel scheme can obviously improve the network performance.

SYSTEM MODEL

In this study, we assume that vehicles are deployed on the road with random deployment, as shown in Fig. 1. Vehicles communicate with each other in the same road segment and can communicate with assisted nodes deployed at the intersection through a short-range wireless channel (100-300 m). The vehicle knows its location through GPS device, which is already popular in new cars and will be common in the future. We assume the road has two directions and vehicles running in the same direction form the transmission network. Each vehicle's neighbor list only contains vehicles running in the same direction. Vehicles exchange beacon messages periodically to get the neighbor vehicles' moving velocity, direction and location, so each vehicle can conduct and update a neighbor list. As shown in Fig. 1, data source S disseminates data information to vehicles in its adjacent area to help drivers nearby know the useful transportation information at S.

RELIABLE AND HIERARCHICAL DATA DISSEMINATION PROTOCOL IN VANETS

Here, both the rapidly topology change and poor connectivity of VANETs are taken into consideration

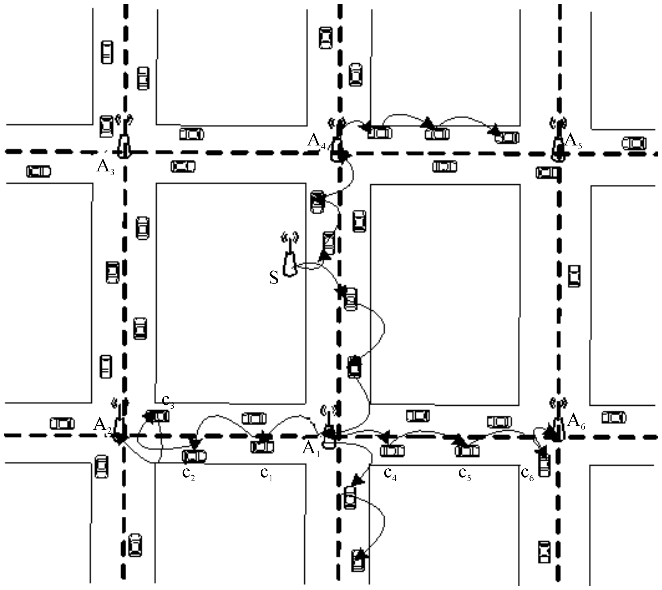

Fig. 1: System model for data dissemination in VANETs

to design the data dissemination scheme. The novel scheme makes use of dynamic prediction to improve the data dissemination reliability among vehicles. Moreover, the assisted node deployed at the intersection is considered to increase the efficiency of data dissemination. To deal with the broadcast storm in VANETs, assisted nodes customize the amount of data according to their distances to the data source. Hierarchical customization is used to satisfy both the communication reliability and the drivers' diverse information requirement.

The scheme presented in this study includes two parts, the reliable data dissemination among vehicles and the hierarchical data dissemination based on assisted nodes.

Reliable data dissemination among vehicles: In present scheme, the data source, by adding forwarder information to the packet header, designates two vehicles in opposite directions to broadcast the data. A forwarder selects one vehicle in its neighbor list and designates the selected neighbor as the next forwarder by adding it to the packet header. The sending forwarder delivers the data to all potential receivers within its one hop range. The next forwarder, after receiving the data, rebroadcasts the data. In this way, the data could be delivered along the propagation direction. As shown in Fig. 2, c_1 is a forwarder and the neighbor vehicles of c_1 include c_2, c_3, c_4, c_5 and c_6. While broadcasting the data to its neighbors, c_1 selects the next forwarder.

The analysis (Bai *et al*., 2012) shows that the connectivity between two vehicles cannot be guaranteed all the time and the connected link could break at times due to the rapidly changing topology. The unreliable link may lead to transmission failure. In this section, the dynamic prediction method is used to increase the reliability of data transmission.

In conventional schemes, the farthest neighbor vehicle which is behind the previous forwarder is expected to be selected as the next forwarder in order to decrease network channel conflict. In Fig. 2, c_6 could be a reasonable choice for c_1. However, due to the change of the relative location between vehicles, there is no guarantee that all the vehicles in the forwarder's neighbor list can maintain in the range of its communication radius during even a minor time interval Δt. As shown in Fig. 3a, because of the relative low speed of c_6, when c_1 broadcasts, c_6 has been out of the communication range of c_1, so the link disconnection would lead to transmission failure. In such a case, c_1 has to reselect a next forwarder and thus it would increase the delivery delay and increase the network traffic overhead. Besides, as shown in Fig. 3b, because of the relative high speed of c_6, when c_1 broadcasts, c_6 has no longer been the farthest vehicle in c_1's neighbor list along the propagation direction. In such a case, although the link between c_1 and c_6 is connected, the real farthest vehicle may be ignored. So, when selecting a next forwarder, a vehicle must guarantee that the selected vehicle would not run out of the communication range of the sending forwarder and it is the farthest vehicle behind the sending forwarder.

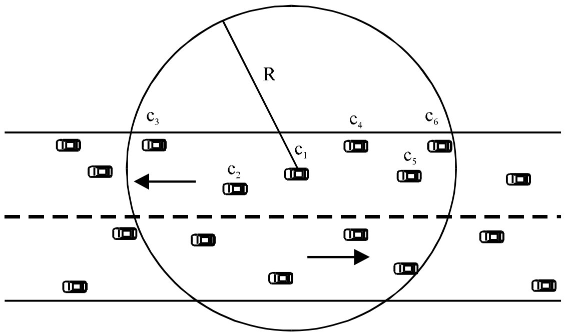

Fig. 2: Data broadcast based on neighbor list

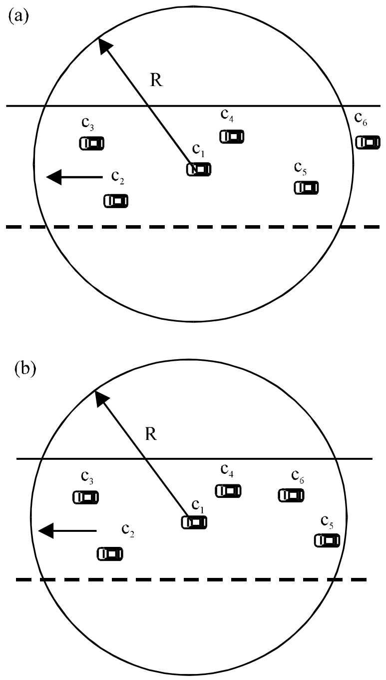

Fig. 3(a-b): Dynamic topology change in VANETs (a) The selected forwarder runs out of the sending forwarder's communication range and (b) The selected forwarder is no longer the farthest vehicle behind the sending forwarder

The transmission direction of a forwarder is the opposite of its travel direction to satisfy the oncoming vehicles' requirement for the information in front. Therefore, we consider the neighbor list of the sending forwarder only contains the vehicles behind it. Assume the location and speed of the sending forwarder c_1 with at time t are $X_i(t)$ and $v_i(t)$, respectively; the location and speed of neighbor vehicles of vehicle c_i are $X_{ij}(t)$ and $v_{ij}(t)$, respectively, $j = 1, 2, \cdots, N(i)$, where $N(i)$ is the number of neighbor vehicles of vehicle c_i at time t. The location of vehicle c_i at time t can be computed as:

$$X_i\,(t+\Delta t) = X_i\,(t)+v_i\,(t)\,\Delta t \qquad (1)$$

The location of vehicle c_j at time $t+\Delta t$ can be computed as:

$$X_{ij}\,(t+\Delta t) = X_{ij}\,(t)+v_{ij}\,(t)\,\Delta t \qquad (2)$$

The condition that vehicle c_j is still in the communication range of vehicle c_i at time $t+\Delta t$ is:

$$|X_{ij}\,(t+\Delta t)-X_i\,(t+\Delta)|\leq R \qquad (3)$$

Therefore, the next forwarder c_1 selected by vehicle c_1 time t can be computed as:

$$1 = \text{argmax}\{|X_{ij}\,(t+\Delta t)-X_i\,(t+\Delta)|\cos\theta_j,\, j\in N\,(i)\} \qquad (4)$$

As shown in Fig. 4a, the farthest vehicle along the propagation direction in the neighbor list of vehicle c_i is vehicle c_1. However, according to the dynamic prediction, vehicle c_1 may run out of the communication range of vehicle c_i, so vehicle c_1 cannot be the next forwarder. Computing by Eq. 4, vehicle c_i selects vehicle c_2 as the next forwarder to ensure that it would not run out of the communication range of vehicle c_j during Δt interval and it is the farthest vehicle behind vehicle c_i.

In addition, because of the rapid change of the link topology in VANETs, it is possible that a forwarder could not find any vehicle behind it in its neighbor list, so this may lead to the link disconnection and the increased delay. In such a case, the forwarder needs the help of a vehicle, which is behind it but in the opposite travel direction, to store and forward the data. As shown in Fig. 5, in the neighbor list of c_1, there is no vehicle with the same direction with c_4 along the propagation direction, so c_5 or c_1 could help to store and forward the data to a vehicle behind c_1 with the same direction as c_1.

The dynamic prediction of the next forwarder improves the data delivery stability and the data dissemination efficiency. Figure 6 illustrates the details of the transmission protocol among vehicles.

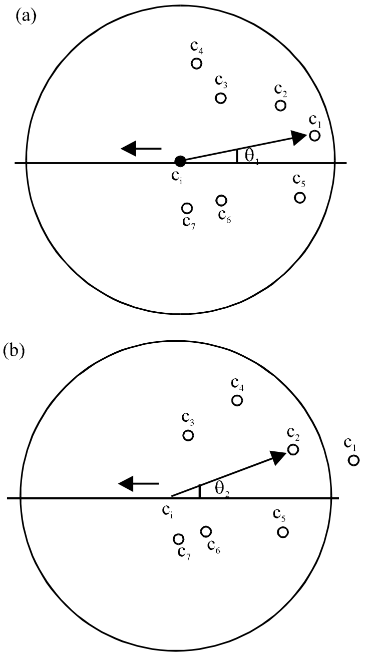

Fig. 4(a-b): Vehicle c_i selects a next forwarder (a) The real distribution of vehicle c_i's neighbor vehicles at time t and (b) The predicted distribution of vehicle c_i's neighbor vehicles at time $t+\Delta t$

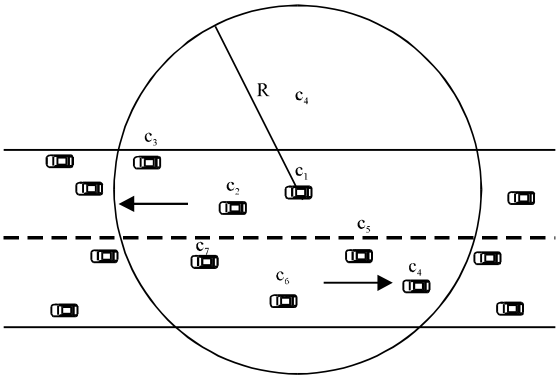

Fig. 5: No vehicle behind the forwarder in its neighbor list

Hierarchical data dissemination based on assisted nodes: With the increase of network vehicle density, the network connectivity can be better. However, much traffic would cause serious communication channel conflict and lead to lower data dissemination efficiency. Moreover, when the data dissemination region increases, more vehicles are expected to receive the data from the data source, which leads to higher probability of the communication channel conflict, data packet loss and longer delivery delay. The assisted nodes installed at the intersection can broadcast the data periodically to

```
Notations:
    $C_i$: The current vehicle
    $C_i$: Nlist[]: The neighbor list of $C_i$
    Fi: The forwarder selected by $C_i$
    Dp ($C_i$, Cj, $\Delta$t): The predicted distance between C and $C_j$ after $\Delta$t
    Rc: The communication radius of the vehicles
    $C_o$: A vehicle behind $C_i$ in the opposite direction in Rc of $C_i$
Periodic probing:
    maxDis = 0;
    Fi <= null;
    for n = 1:sizeof ($C_i$.Nlist)
        candidate <= $C_i$. Nlist [n];
        if Dp ($C_i$, candidate , $\Delta$t)>Rc then
        continue;
    end if
    if Dp ($C_i$, candidate , $\Delta$t)>maxDis then
        maxDis <= Dp ($C_i$, candidate, $\Delta$t);
        Fi <= candidate;
    end if
end for
If $F_i$ is not null then
    add $F_i$ to the message header;
    broadcast the message and designate Fi as a next forwarder;
    delete the message from the buffer;
else
    if $F_i$ is null and there exists Co then
        Fi <= Co;
        add Fi to the message header;
        broadcast the message and designate Fi as a next forwarder;
        delete the message from the buffer;
    else
        continue to hold the message for a time;
    end if
end if
Repeat Periodic Probing when Fi is null
```

Fig. 6: Data dissemination protocol among vehicles

passing-by vehicles to help drivers select a better route. In addition, they can help to store and deliver the data to other assisted nodes farther away from the data source.

The VANET is one of social-proximity *ad hoc* network that drivers at different distances from the data source may not have the same requirement degree for the information. Generally, drivers who are farther away from the data source may not need the data source's complete information, while drivers who are nearer to the data source would like to know more detailed information of the data source.

To lower the network traffic overhead and increase the data dissemination efficiency, a hierarchical data dissemination scheme based on assisted nodes is presented in our study. Figure 7 shows the distribution of assisted nodes deployed at the intersections. The assisted nodes are classified into k grades with the grade number k, k = 1, 2,⋯,. The grade number k equals to the intersection number from the assisted node to the data source. After receiving new data packets, the assisted node customizes the information according to its grade number. When the oncoming vehicles pass by the intersection, the processed information is delivered to them. In Fig. 7, the data source S delivers the data to 1-grade assisted nodes with the help of the multi-hop transmission among vehicles. Then, 1-grade assisted nodes process the data and deliver the customized data to 2-grade assisted nodes. By parity of reasoning, the data packets from the data source are disseminated and delivered to both vehicles and assisted nodes faraway.

In present study, a driver's requirement degree for the data source information is defined as P. According to the intersection number from the data source, P is given by:

$$P = \frac{1}{k+1} \qquad (5)$$

where, k is the grade number of the assisted node, k = 1, 2,⋯. Equation 5 clearly shows the more intersection the vehicle need to pass by to the data source, the less the requirement degree P. For instance, in Fig. 7, the requirement degree of vehicles on the red road section is P = 1/3 and the requirement degree on the road where the data source S locates is P = 1.

An assisted node customizes its received information according to the requirement degree of the drivers nearby, so the amount of data the assisted node broadcast is:

$$M. = pM_0 \qquad (6)$$

where, M_0 is the amount of data the data source generates each period. It is obvious that the farther the distance from the road section to the data source, the fewer amount of data disseminated on that road section. In Fig. 7, the amount of data to disseminate on the red road section is 1/3 M_0.

The data delivery between two assisted nodes is achieved through multi-hop transmission among vehicles on the road. When the network is completely connected, an assisted node would probably receive data packets from all different directions. In such a case, if the assisted node receives the data which is generated from the same data source but later than the data it holds, the assisted node would discard the old data and store the new one. And if the assisted node receives the data which is generated from the same data source at the same time but with larger amount of data, the assisted node would also discard the old data and store the new one.

However, due to the connectivity cannot be guaranteed, the disconnection would lead to the failure of

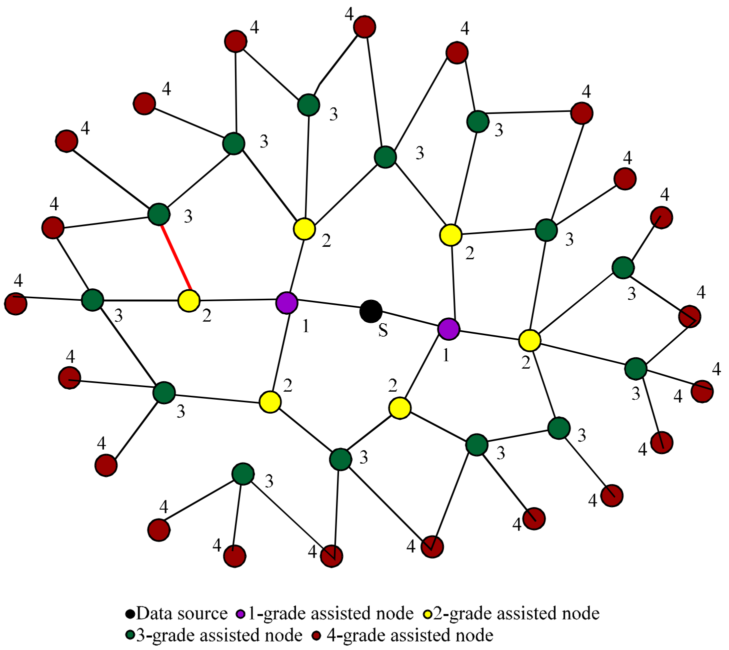

Fig. 7: Distribution of assisted nodes deployed at the intersections

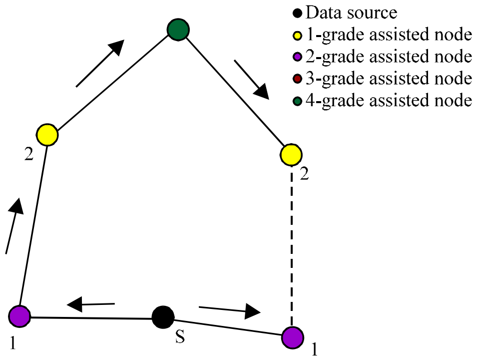

Fig. 8: Degradation of assisted nodes

data delivery from one assisted node to another. Therefore, an assisted node can possibly receive the data information from the assisted node with the same grade or lower grade. As shown in Fig. 8, if the network between the right-side 1-grade assisted node and 2-grade assisted node is disconnected and all networks on other roads are connected, the amount of data received by the right-side 2-grade assisted node is 1/4 M_0. In such a case, it actually becomes a 4-grade assisted node and we call this phenomenon the degradation. The degraded assisted node would not customize the amount of data.

Although, the amount of data broadcasted by the degraded assisted node is less than that broadcasted by the assisted node in normal circumstance, this will not affect the data reception of the vehicles nearby severely. This is because when the vehicles come into a region closer to the data source S, they would receive more detailed information broadcasted by higher-grade assisted node. As shown in Fig. 8, when a vehicle passes through the right-side yellow assisted node and enters the dotted line road section, it would receive the more detailed data information broadcasted by the right-side 1-grade assisted node.

An assisted node, after receiving and processing information, broadcasts the customized data and deliver the data to vehicles in all required directions. Figure 9 illustrates the details of the transmission protocol of assisted nodes.

PERFORMANCE EVALUATION

In this section, in order to show the superiority of HADD presented in this study, we compare the performance of HADD with other three typical data dissemination scheme, i.e., the Flooding Dissemination Scheme (FLOOD), the Assisted-node-based Data Dissemination Scheme (ADD) and the no assisted Node Data Dissemination Scheme (NADD). By simulation, it is clear that HADD increases the network performance in terms of data dissemination rate and delay obviously.

Simulation model: We developed the Matlab-based Vehicular Network Simulator (MVNS) to evaluate the

```
Notation:
        Ah: the current assistant node
        Ah.Nlist[]: the neighbor list of Ah inluding the oncoming vehicles only
        Dp(Ci, Cj, Δt): the predicted distance between Ci and Cj after Δt
        RA: the communication radius of the assisted nodes
        Nrd: the number of roads containing oncoming vehicles which need the message and the number of roads connected to the Intersection is (Nrd+1)
        Mr: the message received by Ah
        Mc: the customized message of Mr by Ah
        Mr.grade: the customization times of t he message Mr before
        Fah[n]: the selected forwarder on the nth road among Nrd roads
Periodic Probing:
        Fah[] is all set to null;
        if Ah.grade equals to (Mr.grade+1) then
                Mc <= the customized message of Mr;
                Mc.grade = Mr.grade + 1;
        else
                Mc <= Mr;
        end if
        for n = 1: Nrd
                maxDis = 0;
                for m = 1:sizeof(Ah.Nlist)
                        candidate <= Ah.Nlist[m];
                if Dp(Ah, candidate, Δ t) > RA then
                        continue;
                end if
                if Dp(Ah, candidate, Δt)>maxDis then
                        maxDis = Dp(Ah, candidate, Δt);
                        Fah[n] <= candidate;
                end if
        end for
        if FAh[n] is not null then
                add FAh[n] to the message header;
                end if
        end for
        broadcast the message and designates FAh as next forwarders
        Repeat Periodic Probing at the next broadcast interval orwhen Ah receives a new message
```

Fig. 9: Data dissemination protocol of assisted nodes

proposed schemes. The MAC layer and the physical layer of the wireless network base on an open project wireless network simulator (WNS).

The simulation area is a 3800×3800 m^2 region. There are 4 horizontal roads and 4 vertical roads in this region and hence 16 intersections. The length of each road section between 2 intersections is 1200 m.

To simulate the vehicle traffic on the roads, we initially randomly deploy 760 vehicles on the road (vehicle density λ is 25 vehicles/kilometer) and let them move with the changing speed $V\in[15, 80]$ mi h^{-1}. Those vehicles, when meeting the intersection, randomly select a direction from left, right and front to move on. When the vehicle arrives at the edge of the simulation region, it moves back in order to mimic a continuous traffic flow. Figure 10 shows a snapshot of the simulation area. The red pentagram stands for the data source and assisted nodes are deployed at each intersection. The blue circle stands for the communication radius of a vehicle.

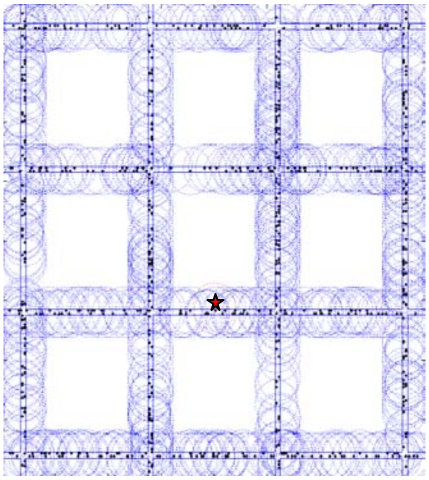

Fig. 10: Snapshot of the simulation setup area

Table 1: Experiment parameters of network performance evaluation

Parameter	Value
Simulation time	300 sec
Simulation area	3.8×3.8 km
Total number of vehicles	760
Communication radius of vehicles	200 m
Communication radius of assisted nodes	200 m
Vehicle density	25 per kilometer
Data packet size	2500 bit
Data source broadcast cycle time	2 sec
Vehicle speed	15~80 mi h^{-1}
Data amount of source S	100~700 packets
Beacon interval	2 beacon/sec
Control packet size	512 bit

The data packets are sent by the data center repeatedly. In this study, the data packet is considered to be with a fixed size of 2500 bits. Each vehicle sends beacon message every 0.5 sec to report its own location and speed.

For each measurement, 30 simulation runs are used and each simulation run lasts for 300 seconds. Most experiment parameters are listed in Table 1.

Data dissemination efficiency in VANETs: The performance of the schemes is measured by the following metrics.

Data dissemination rate: For each vehicle, the data dissemination rate is the total number of the received nonidentical data packets divided by the total number of the dissemination data packets broadcasted by the data source.

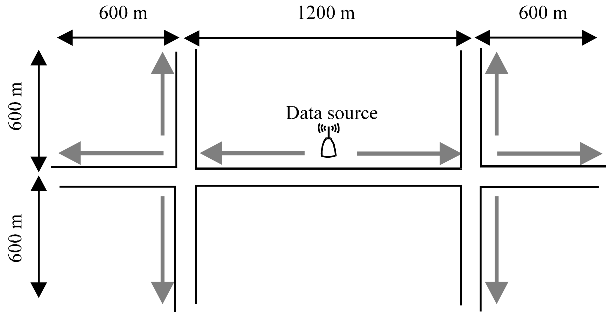

Fig. 11a: Road layout 1 includes two 1-grade assisted nodes

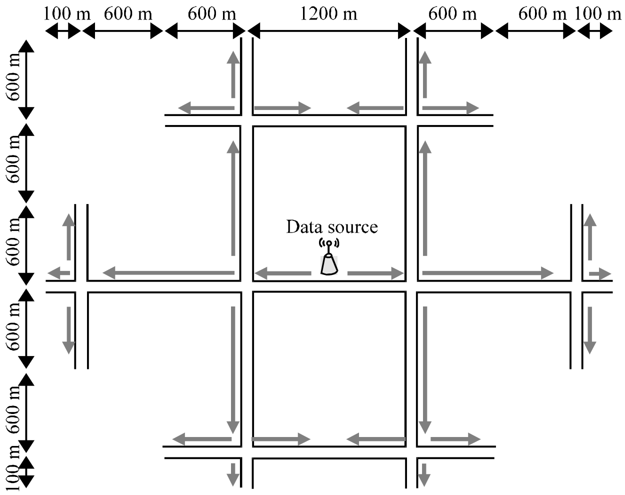

Fig. 11b: Road layout 2 includes two 1-grade assisted nodes and six 2-grade assisted nodes

Data dissemination delay: For all the received data packets of each vehicle, the data dissemination delay of the vehicle is the average time interval from each data packet's generation time to the receipt time.

Two types of road layouts intercepted from our simulation area implemented to evaluate the data dissemination rate. Figure 11a shows the road layout I including two 1-grade assisted nodes and Fig. 11b shows the road layout II including two 1-grade assisted nodes and six 2-grade assisted nodes. The gray arrow stands for the data delivery direction.

Figure 12 shows the relation between the dissemination rate and the amount of data broadcasted by the data source periodically, when the network density is 25 vehicles per kilometer and the communication radius is 200 m. Figure 12a shows the data dissemination rate when the simulation is implemented on road layout II and Fig. 12b shows the data dissemination rate when the simulation is implemented on road layout II.

It is clear to see that the schemes based on assisted node (HADD and ADD) have a relatively higher data dissemination rate. This is because with the help of the assisted nodes, the chances to disseminate data in the network increases greatly.

When the amount of data increases, there is much more network traffic, which lead to severe channel conflict. The data dissemination rates of these four schemes decrease obviously. HADD customizes the amount of data according to drivers' requirement degree to avoid redundant data and communication channel conflict and thus HADD has the highest data dissemination rate, especially when the amount of data becomes larger. For instance, when the amount of data is 600 packets, the data dissemination rate of HADD is 0.71, which is higher than that of the other three schemes. The data dissemination rate of FLOOD drops faster than the other schemes when the disseminated data packets increase. As for FLOOD, more vehicles are involved in

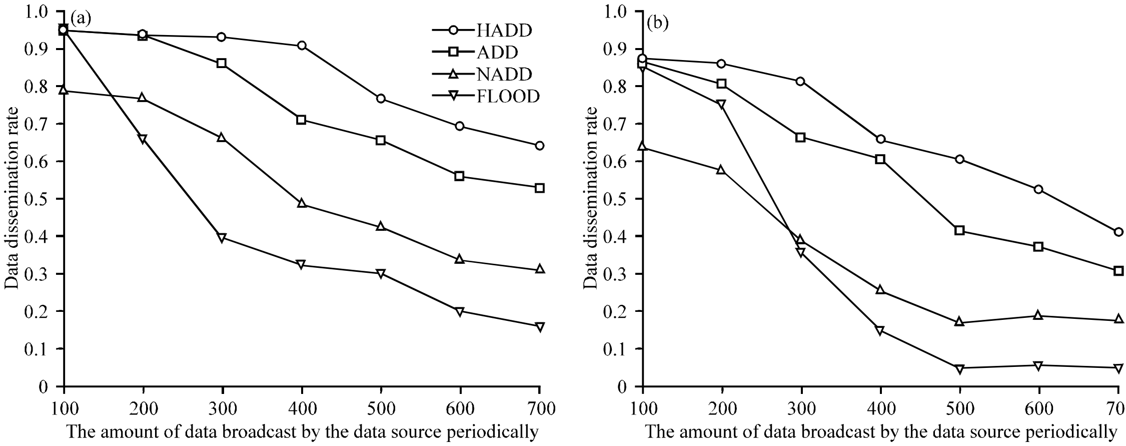

Fig. 12(a-b): Relation between the data dissemination rate and the amount of data, (a) Road layout 1 and (b) Road layout 2

rate decreases. When the amount of data is 500 packets, the HADD's data dissemination rate on road layout I is 0.76, while the HADD's data dissemination rate on road layout II is 0.6. This is because when transmission distance is longer, the network connectivity is worse, more channel conflicts occur, the data packet loss increases and hence the lower data dissemination rate.

Figure 13 shows the data dissemination delay of vehicles at three different locations (600, 1800 and 3000 m away from the data source) using HADD, ADD and NADD. When the dissemination distance is 600 m, three schemes have nearly the same delay. This is because the dissemination distance is within the location of 1-grade assisted nodes and assisted nodes cannot help to deliver the data. When the dissemination distance is larger, the delay increases and HADD has the smallest delay and NADD has the largest delay. For instance, when the dissemination distance is 1800 m, HADD's delay is nearly 0.59 sec and NADD's delay is nearly 1.15 sec.

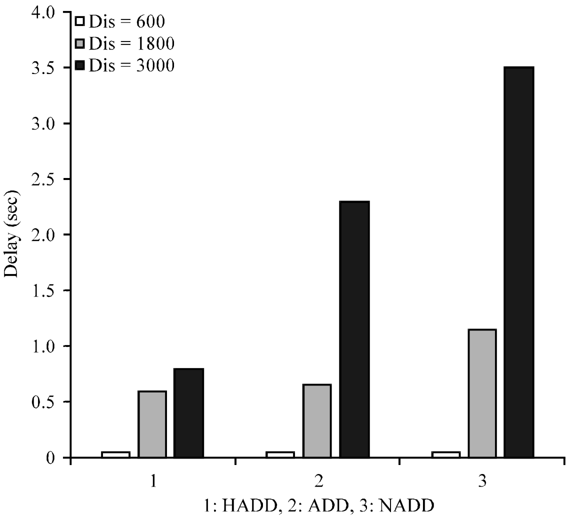

Fig. 13: Date Dissemination delay at different distances from the data source

From the above analysis, it is clear to see that HADD can obviously improve the network performance of data dissemination rate and delay, comparing with other dissemination schemes. In FLOOD, more vehicles are involved in data delivery and lead to more redundant data and severe channel congestion. Moreover, due to the network topology rapid change, the network connectivity is worse, which incurs serious packet loss. Different from FLOOD, the other three schemes use the prediction method to improve the stability of communication channel. As for HADD, before the data is transmitted by the assisted node, the amount of data is customized according to the different requirements. The assisted node is used to customize the amount of data to reduce the channel conflict and increase the data dissemination efficiency obviously.

CONCLUSION

Due to the unique characteristic of VANETs, such as dynamic network topology and poor connectivity, reliable and efficient data transmission is difficult to realize. In our study, the reliable and hierarchical data dissemination scheme based on assisted nodes is studied. The dynamic prediction scheme is useful to guarantee the reliable data delivery among vehicles and assisted node based scheme could help to increase the network connectivity and data dissemination efficiency. The drivers' requirement degree is taken into consideration to design the hierarchical data dissemination mechanism. The simulation results show our novel scheme increases the network performance in terms of data dissemination rate and data dissemination delay.

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