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RSUs Aided Data Dissemination Scheme for Vehicular Adhoc Networks

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Abstract: Key focus of RSU deployment for vehicular ad-hoc networks is typically on minimization of deployment cost while still ensuring maximized enhancement of network performance. A hotspot-based RSU deployment scheme is firstly proposed in this study. Multiple RSU is placed along road to form a backbone link and these links are placed between hotspot regions to connect these "isolated island" for maximized enhancement of network connectivity. A RSU based data dissemination scheme is also proposed in this study. Vehicles use the probability flooding method to diffusion RSU location and vehicles outside the wireless transmission range of RSU also can use RSU to forward the packets. The simulation results show that our scheme can achieve more significant and better performance compare to the existing RSU deployment and data dissemination scheme.

Key words: Vehicular ad-hoc network, RSU, data dissemination, hotspot, connectivity

INTRODUCTION

As an important component of the Intelligent Transportation System (ITS) and a novel form of mobile ad-hoc network, Vehicular ad-hoc networks (VANETs) have attracted much attention from government, academia institutions and enterprises. As is shown in Fig. 1, A Vehicular Ad-Hoc Network (VANET), which is a form of Mobile ad-hoc network, providing communications among nearby vehicles and between vehicles and nearby fixed equipment, usually described as roadside units (RSUs) (Ghandeharizade *et al*., 2004). The applications of VANETs can be divided into two major categories (Banerjee *et al*., 2008; Lu *et al*., 2010; Do *et al*., 2010): Safety and non-safety. Safety applications include collision and other safety warnings, which can be further categorized as safety-critical and safety-related applications. Non-safety applications include real-time traffic congestion and routing information, high-speed tolling, mobile infotainment and many others.

In order to achieve the maximized network performance enhancement with the limited cost, the RSU Deployment Scheme (RDS), which is an optimization methodology to find a proper location for RSU deployment is proposed in this study. We use the network connectivity as a measure of network performance while the RSU deployment efficiency is defined as the ratio that network connectivity and the deployment cost (No. of RSU). The simulation shows that proposed method can achieve better deployment efficiency than existing methods.

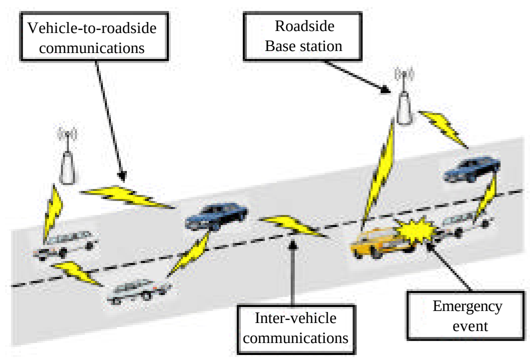

Fig. 1: An illustration of VANETs

This study proposes RSU based Data Dissemination (RDD), using the probabilistic flooding method spread the location information of RSU in the network, making the vehicles that are located outside the wireless transmission range of the RSU informed of the RSU location, then, the performance of data dissemination can be improved.

The remainder of this study is organized as follows. In section 2 we review related work. Following that, in section 3 we introduce some relevant definitions and

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assumptions. We show the detailed description of the proposed RSU deployment scheme in section 4 and the data dissemination scheme in section 5. The simulation results and analysis in a city scenario are demonstrated in section 6. Finally, we conclude the study with a summary in section 7.

MATERIALS AND METHODS

Many recently proposed VANET travel comfort or traffic flow applications rely on some form of data dissemination and aggregation. In this section we discuss existing scheme about RSU deployment and the method that RSU-based data forwarding, then we analyze the performance of each method.

It has been discussed in the literatures Ott and Kutscher (2004) and Das *et al*. (2004) to improve network connectivity and data dissemination by adding comparatively inexpensive infrastructure (RSU) at some locations in a city and the RSU has a wide range of applications. The issues are that How to deploy the RSU effectively to minimize the cost of deployment and How to make efficient data dissemination RSU-based.

Several schemes (Banerjee *et al*., 2008; Lu *et al*., 2010) were proposed in which the high-density node region was taken as the priority location for RSU deployment. In (Banerjee *et al*., 2008), mobile network consists of an average of 20 transit buses on the road 18 h day^{-1} in an area of about 360 square kilometers. They deployed three different kinds of networks and concluded that a small amount of infrastructure in certain cases is vastly superior to even a large number of mobile nodes capable of routing data to one another. Lu *et al*. (2010) who think that the shortest paths between nodes are more frequently with more traffic, mapped the road network to a graph. In these locations they have the priority to deployed RSU so that the signal can cover more nodes and maximize the improved network performance.

Some people use the centrality of social network theory to optimize RSU deployment strategy. They establish vehicle nodes connected graph and calculate the centrality of each node (edge) to determine whether there is part of nodes (edges) have a more important role in the total network traffic. Do *et al*. (2010), based on node density, cluster size and node centrality measures the deployment strategies of the RSU. They analyze the node number that are covered by RSU by using the low (high) density-priority, low (high) centrality-priority, centrality-density balance and random deployment strategy. Kchiche and Kamoun (2010) use the metric that degree centrality, closeness centrality, betweeness centrality to analyze RSU maximum coverage problem.

Zhao *et al*. (2008) propose a vehicle-to-vehicle relay (V2VR) scheme which extends the service range of roadside APs and allows drive-thru vehicles to maintain high throughput within an extended range. The result demonstrates that the method solution handles high vehicle mobility well and allows drive-thru vehicles to maintain high throughput in the extended AP coverage area from 60-100 m. To improve data delivery performance, Ding *et al*. (2007) propose SADV, which utilizes some static nodes at road intersections in a completely mobile vehicular network to help relay data. With the assistance of static nodes at inter-sections, a packet can be stored in the node for a while and wait until there are vehicles within communication range along the best delivery path to further forward the packet, which reduces the overall data delivery delay. The forwarding method can lead to a better performance, the disadvantage is that there will be a need to deploy a large number of RSU and the delayed information dissemination needs to take up extra bandwidth, besides, RSU forwarding algorithm is very complex.

DEFINITIONS AND ASSUMPTIONS

Assumption: We suppose the time is discrete that t = 1, 2... is the discrete timeslot in seconds and geographical space is divided into n×m square grids where row r and column c are denoted by $grid_{rc}$.

Definition 1 (connected graph): Use the undirected graph $G_t = (V, E)$ to represent the network connectivity at time t. V is vertex set, $|V| = N$ is the number of nodes, E is the edge set, the edge (u, v) denotes that the Euclidean distance between the node u and v is less than the node's wireless transmission range TR (Transmission Range) and the node can establish a wireless link and transfer data.

Definition 2 (node connectivity): Node connectivity in the network refers to the ratio of the corresponding vertices in the connected components and the total number of vertices in the connectivity graph G_t, that is the node's proportion which can be reached by a node through multi-hop, the connectivity of node u is denoted by D_u:

$$D_u = \frac{|C|}{N} \tag{1}$$

In Eq. 1 C is the connected cluster of node u.

Definition 3 (Network Connectivity): Network Connectivity refers to the mean of node connectivity in the network, it is denoted by D:

$$D = \frac{1}{N}\sum_{i=1}^{N} D_i \qquad (2)$$

RSU DEPLOYMENT SCHEME BASED ON HOTSPOTS

The optimal selection method of RSU deployment location is divided into three steps, the first step is to discover the "hot spots" area by pre-acquisition vehicle traces; then build the hotspot-relation graph according to its size (average number of nodes) and the geographical distance; at last, using the maximum spanning tree algorithm to calculate RSU deployment location based on the hotspot-relation graph:

- **Step 1:** Find hot spot. Assuming the format of vehicle trace data is P = [id, t, la, lo]. There, id is the vehicle identifier, $t \in [0, \tau]$ is the discrete timestamp and la and lo are the vehicle location's latitude and longitude coordinates. Calculate location information about the number of vehicles in the $grid_{rc}$ denoted by n_{rc} (t) in the geo-spatial grid for each vehicle. Then, calculate the mean of n_{rc} (t) at the time $t_0, t_1, \ldots t_\tau$, set the threshold value $n_{threshold}$ and we can get higher vehicle density's grid set $HS = \{grid_{rc} | \overline{n}_{rc} > n_{threshold}\}$. Adjusting the threshold $n_{threshold}$, different numbers of hotspots area that are denoted by k can be obtained
- **Step 2:** Establish hotspot-relation graph. The undirected weight graph H = (V, E) represents the relationship between each hot spot. V is the node set denoting hot spot, E is edge set, edge weights w_{ab} represent the efficiency of a backbone link deployed between two corresponding hot spots and efficiency is defined as the ratio between the connectivity enhancement effects and deployment cost. Calculate edge weights by the approximate method, using the ratio between the node number in two "hot spot" areas and geographic distance instead. The calculating formula is as follows:

$$w_{ab} = \frac{N_a + N_b}{distant_{ab}} \qquad (3)$$

N_a and N_b are the node number in two "hot spot" areas, $distant_{ab}$ is the distance among two hot spots area, establish an adjacency matrix $C = (C_{ij})_{k \times k}$ and then calculate the efficiency of every link between the two hot spots and store into the corresponding matrix elements according to Eq. 3
- **Step 3:** Determine RSU deployment location. RSU deployment is aimed to determine the minimum number of the deployment, while maximize network connectivity. We can transfer the issue based on hotspot-relation graph into solving the maximum spanning tree of hotspot-relation graph. This is, to get the spanning tree with maximum edge weights of graph H, which can be solved by Prim algorithm. Prim algorithm is based on the greedy algorithm, its process is as the following: First, choose a vertex v_0 and then connect with the far vertex (the maximum weighted edge), so sub-tree T_1 is obtained; then connect to sub-tree T_2 of the vertex v_2 with the farthest distance from T_1, the process is not iterated until each vertex is connected, that is to form the maximum spanning tree diagram. It is proved that the tree spanned by Prim algorithm has the maximum edge weights, that is, RSU backbone network has the maximum deployment efficiency. The procedure of algorithm is as the following:

- T_0: The set storing spanning tree 's edges, the initial state is $\varnothing$
- V': The set of the vertices which has been added
- L (v): The distance from the vertex v to the sub-tree T_0
- C (T_0): The weight of the maximum spanning tree, the initial value is 0

The input of the algorithm is the hot spot diagram's adjacency matrix $C = (C_{ij})_{n \times n}$:

- $T_0 \leftarrow \varnothing$, $C(T_0) \leftarrow 0$, $V' = \{v_0\}$
- for a vertex $v \in v\text{-}V'$, $L(v) \leftarrow C(v, v_0)$ (if $(v, v_0) \notin E$, then $C(v, v_0) = \infty$)
- If V = V', output T_0, C (T), the algorithm stop, else turn to the next step.
- Find a vertex u in V-V' to make L (u) = Min $\{L\{v\} | v \in (V\text{-}V')\}$ and take down the vertex u 's neighbors vertex w, e = {w, u}
- $T_0 \leftarrow T_0 \cup \{e\}$, $C(T_0) \leftarrow C(T_0) + C(e)$, $V' \leftarrow V' \cup \{u\}$ (6)for a vertex $v \in V\text{-}V'$, if $C(v, u) < L(v)$, then $L(v) \leftarrow C(v, u)$, else L (v) is invariant
- Go to (3)

After determining the maximum spanning tree, calculating shortest path between the corresponding two hot spots in road topology for each edge of the tree, then the RSU deployment location can be got.

RSU BASED DATA DISSEMINATION SCHEME

The process of RSU-based Data Dissemination Scheme is as the following: RSU periodically broadcasts beacon messages about the identifier and location of the RSU. The node within cover range of RSU receives the message respond to a message to connect with the RSU and use the probability of flooding method diffusion information of RSU, that is, each node received RSU message broadcasts the message by the probability p to the neighbor. Probability of information is forwarded to the number of forwarding is a negative exponential function, that is, the probability p increases with the number of forwarding decline rapidly. The further away from RSU, the smaller the forwarding probability will be. The mechanism allows the nodes outside the wireless transmission range of RSU also be informed of the information near the RSU. We can adjust the parameters of forwarding probability function to ensure the broadcast is limited to local scale, to avoid the waste of network resources and broadcast storms.

Before the node forwards packets, it firstly checks whether they received RSU information. If the nodes do not receive the RSU information, it will be selected from neighbor nodes that the distance from the destination is the nearest as the next hop relay forwarding. If the RSU information has been received, it will indicate the node is close to the RSU, the vehicle first calculates the distance from the destination node and then sends a message to the RSU for querying whether more recent node exist away from the destination node in the RSU backbone network. After receiving the results, the vehicle according to the minimum distance principle will decide whether the use of RSU-assisted packet forwarding.

RSU information diffusion:

RSU information format is below.

In the Table 1, RSU id is the identifier of RSU, la and lo is the latitude and longitude coordinates of RSU, hop is the number of information which has been forwarded. RSU broadcasts RSU messages periodically through beacon messages, the vehicle broadcasts the information received to neighbor nodes according to the probability p forwarding probability p is the forwarding number's negative exponential function, calculation formula is as follows:

$$p = e^{-c*hop} \tag{4}$$

Table 1: RSU information format

RSU id	la	Lo	hop

Table 2: Pseudo-code of RDD algorithm

```
if (RSU info = null)
 node next = NextHop(thisnode.neighbor);
 forward m to node next;
Else
 double d1 = distant (ThisNode, RSU)
 send query to RSU;
 receive d2;
 If (d1 ≥ d2)
 send m to RSU;
 exit;
 end if;
 node next = FindProperNext (this node.neighbor);
 forward m to next;
end if;
```

In the equation, c is a constant parameter. Node will keep it when it receives RSU location information for routing strategy of the forwarding packet. Meanwhile, the lifetime of information is set as t_{live}, if new information is not received during the life period , then it will be thought as having been away from the RSU and will be deleted.

Packets forwarding: Assuming the vehicle node knows the location of the destination node and each RSU has stored the positions of all RSU and backbone topology information. When the node forwards the packet, firstly, it checks whether it has stored the information of RSU, if it has not, then it will select the closest neighbor node from the destination node as the next hop. If the node have got the message, then it will calculate the distance d_1 from its destination node and sends query messages with the destination location to RSU. After RSU receives the message, it calculates the location of RSU which is the nearest from the destination node and the distance d_2 in the backbone network and returns the d_2. When vehicle nodes receive the query result, d_1 will be compared with d_2,

If $d_1 \le d_2$, there is no need for us to use RSU auxiliary for forwarding packet, the vehicle find a suitable neighborhood node as next hop relay. If $d_1 > d_2$, the vehicle will send the packet to the RSU for forwarding. After data packets are forwarded to the nearest RSU by RSU backbone network, the RSU will select the nearest vehicle as the next-hop node. The flowing chart of the algorithm is shown in Fig. 2.

The pseudo-code of forwarding algorithm is given in Table 2.

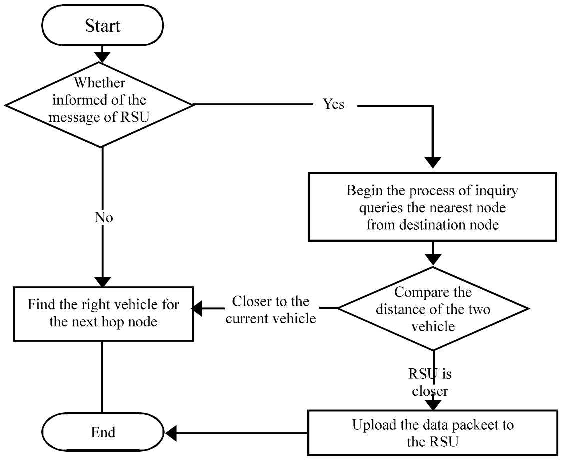

Fig. 2: Process of packet forwarding

SIMULATION AND ANALYSIS

To better understand the impact of the RSU placement scheme in a real mobile network, we perform a systematic study of RSU in a large-scale vehicular network.

We have emulated and analyzed for technical program based on the real vehicular traces. The simulation tool is developed by the Helsinki University of Technology. It is an open-source and Java-based environment simulation tools called ONE (Opportunistic Network Environment simulator). The specific parameters of simulation are in Table 3.

We run the experiments by using a mobility trace of the taxi for the city of San Francisco, USA. Vehicle trajectory data set is 536 taxis within 23 days of running. Each car is equipped with GPS and they can obtain real-time location information in the format [id, timestamp, lo, la, state]. The id stand for the number of identity, timestamp is the current time, lo and la are the coordinates of latitude and longitude of the vehicle position, state representatives whether carrying passengers currently, the time accuracy is 1 second and the location accuracy is 1×10^{-6} degree.

As time interval of acquisition of the vehicle location information is too long (about 60 sec), we need to have the pre-processing about the original data set. First of all, from the U.S. Census Bureau's TIGER data base contains the electronic map of San Francisco. We select the size of the area as simulation area (longitude [122.379000, 122.509000], latitude [37.703000, 37.813000]). The simulation area contains 14,264 straight road and 6529 curved roads approximated by a number of road segments.

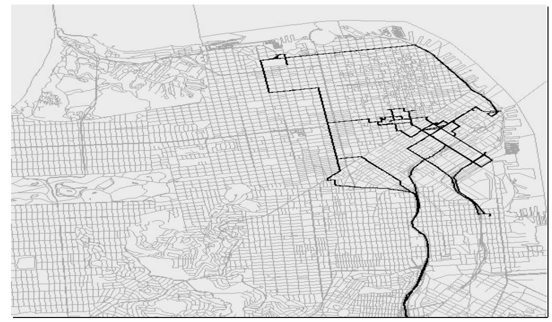

Fig. 3: Vehicular trace

Table 3: Simulation parameters setting

Parameters	Value
Simulation area	13×11 km
No. of vehicles	536
No. of roads	20793
RSU transmission range	300 m
Node transmission range	300 m
Data packet size	2 KB
Sending interval of each data packet	10 sec
RSU buffer size	50 MB
Hotspot threshold	50~2000
Node routing protocol	GPSR
Node buffer size	1 MB

We have the map-matching to these track points that falls outside of the road. The specific method is projection the vehicle position to the neighboring road; choose the path with minimum projection distance, the point where the vehicles is projective on the road as a matching position. Accordance with the principle of shortest distance, we using Dijkstra algorithm acquire the missing track interpolation among the two locations. Through the method we have acquired the full vehicle trajectory with 1s of time granularity. The 2 h of complete travel path of a taxi have been pre-treated shown in Fig. 3.

Performance analysis of RDS: First, we use geographic grid whose size is 100×100 m to have simulation region discretion and use the vehicle trace in 2 h to run simulation. We calculated the number of vehicular position point in each grid and use it to estimate the density of vehicles. The results are shown in Fig. 4, the vehicle's location points in a small part of the grid up to more than 1000, most of the number of grid following 50. It shows the extreme uneven features of spatial distribution of nodes, there are obvious "hotspot" phenomena.

Figure 5 shows the efficient of enhancement connectivity of RDS and the regular deployment scheme. It can be observed from the figure that: (1) Network connectivity of RDS has a significant enhancement.

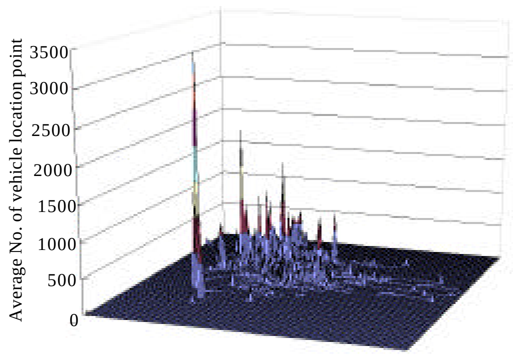

Fig. 4: Density distribution of vehicles

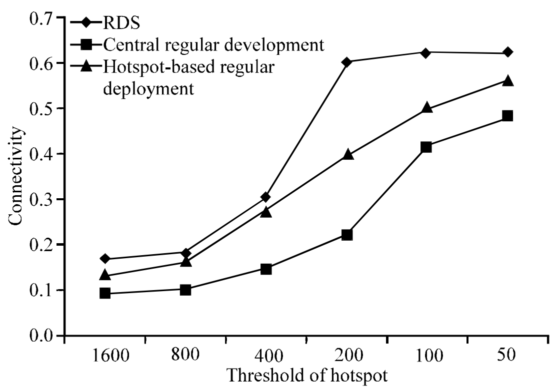

Fig. 5: Network connectivity of two RSU deployment scheme

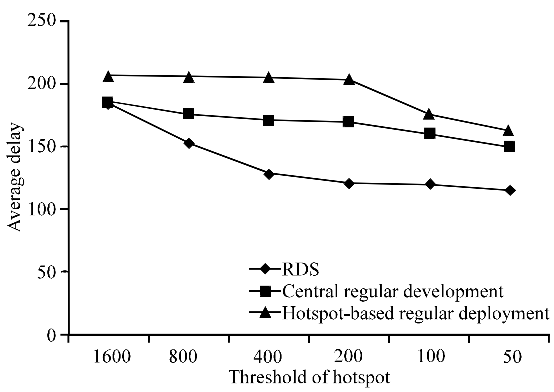

Fig. 6: Average delay

When the Threshold of hotspots is 1600, we place13 RSU, network connectivity is 0.168. The threshold value is 200 we deploy 81 RSU; network connectivity increases to 0.597, (2) Among the three deployment schemes, RDS has the best network connectivity. The hotspot-based regular deployment is obviously better than the central regular deployment, (3) When taken threshold of hotspots is in the range from 200-1600, using RDS deployment scheme with the rapid growth of network connectivity. When the threshold value was from 50-200, although there is a significant increase in the number of RSU, the connectivity to obtain without the corresponding increase was maintained within the range from 0.59-0.62. It is because when the threshold value is less than 200, the number of nodes in "hot spots" is small, geographic distribution is more scattered, these hot spots need to connect with a large number of deployed RSU. Relatively small number of nodes be connected, the use of RSU backbone link connecting these "hot spots" on the network connectivity is not obvious, so it can not be an ideal deployment efficiency.

Performance analyses of RDD: We have analyzed the performance of the RSU-based data dissemination scheme. There are two simulation scenarios. One is RSU-based data dissemination scheme under the deployment of RDS. The other uses the regular deployment. In second scenarios, the vehicle in the range of wireless transmission of the RSU as a direct access node. It can ask the RSU whether the existence of the node that from the destination node is closer. In addition that the node cannot learn RSU information, so we should use the GPSR protocol to find a neighbor closer to the destination as the next hop for forwarding. Figure 6 shows the average delay of packet forwarding. The RDD can obtain the best delay performance, with the hotspot threshold reduces and increases in the number of RSU, the average delay from the 183 sec down to 120 sec. However further increase the number of the RSU, reduce the average time delay effect is not obvious. Meanwhile, the RSU matrix placed in the hotspot, covering the number of vehicles more than the number of nodes of central regular deployment, so the hotspot-based regular deployment delay performance is significantly higher than the central regular deployment.

CONCLUSION

How to ensure maximized enhancement of network performance under limited deployment cost is a challenging problem in VANETs. We present a hotspot based RSU deployment scheme, which can effectively improve network connectivity, while use the small amount of RSU. RSU based data dissemination is proposed which allows vehicles outside transmission range of RSU to obtain the location of RSU and use RSU to forward packets. The simulation results show that our RSU deployment has better network connectivity than the existing RSU deployment scheme and our RSU based data dissemination scheme can effectively reduce the delay of packet forwarding.

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