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Efficient Deployment of RSUs in Smart Highway Environment

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Abstract

Vehicular density is usually low in a highway environment. Consequently, connectivity of the vehicular ad hoc networks (VANETs) might be poor. We are investigating the problem of deploying the approximation optimal roadside units (RSUs) on the highway covered by VANETs, which employs VANETs to provide excellent connectivity. The goal is to estimate the minimal number of deployed RSUs to guarantee the connectivity probability of the VANET within a given threshold considering that RSUs are to be allocated equidistantly. We apply an approximation algorithm to distribute RSUs locations in the VANETs. Thereafter, performance of the proposed scheme is evaluated by calculating the connectivity probability of the VANET. The simulation results show that there is the threshold value M of implemented RSUs corresponding to each vehicular network with N vehicles. The connectivity probability increases slowly with the number of RSUs getting larger.

Keywords: *VANET, RSU deployment, Approximation algorithm, Smart highway*.

1. Introduction

VANET is a type of mobile ad hoc network (MANET), which includes vehicle-to-vehicle and vehicle-to-infrastructure communication. Drivers can receive over-the-horizon traffic information through inter-vehicular communication. This information helps the drivers avoid traffic accidents and congestion. It also can keep the traffic under control, thereby enabling faster movement of vehicles. Additionally, VANET provides conditions for working and entertaining in a vehicle on the trip, which can help in the elimination of the feeling of the

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blockade and dullness experienced during travels. These ad hoc networks therefore improve the quality of life and work efficiency. With the rapid development of wireless communication technologies, vehicle embedded computing, along with the various types of vehicle sensors, VANET has the potential for wide applications [1].

VANET has attracted the close attention of the research institutes and researchers worldwide [2]. In the initial stage of VANET development, data transmission in the network was mainly conducted through vehicle nodes equipped with on-board computing devices, wireless communication devices, and various sensor devices [3]. A vehicle node not only acts as the source and destination node, but also has the function of forwarding messages. These notes forward data to long-distance vehicles through the multi-hop scheme. With the further development of the VANET technology, researchers have introduced the concept of roadside unit (RSU) to assist vehicle data transmission [4]. The roadside node can be either a wireless communication base station, or an Internet gateway providing communication links for vehicles and traffic management departments.

In the environment of a highway, the accident rate is generally higher than that of an ordinary road owing to the high speed of vehicles. With the use of the VANET technology, the probability of vehicle accidents on highways can be greatly reduced, thus ensuring a secured environment for safe driving. First, it can reduce the probability of car rear-end collisions. The vehicle rear-end collision is a frequent traffic accident on highways. The main reason is that drivers cannot stop a moving vehicle immediately in the case of an accident. Accidents can be avoided if the front vehicle sends the emergency warning message to the rear high-speed vehicle in a timely and reliable manner reminding the rear vehicle to brake ahead of time. Secondly, it can provide assistance in driving in the case of bad weather conditions. It is easy to cause traffic accidents because of the low visibility while driving a car when there is the bad weather such as rain, fog, or snow. If each vehicle transmits driving information to each other, the driver will be warned if the distance between vehicles is not within the safe distance limits. This information can provide timely driving assistance for drivers. Third, it can provide early warning of the presence of accident-prone sections. Although necessary warning signs such as speed limit and stop ban have been set up in accident-prone sections of expressways to remind drivers to pay attention to the traffic safety, warning signs have limited warning effect on drivers. If roadside nodes are deployed at warning boards, warning messages can be transmitted to high-speed vehicles in time before the driver passes through these specific sections. It can warn the driver to reduce the speed earlier, thereby, it can greatly improve the warning function.

2. Related works

In VANET, roadside units are deployed to support information transmission, which has received considerable attention from researches in the recent years. An RSU deployment scheme is presented based on the priority of intersection in literature [5, 6]. They calculated the optimal number of RSUs to minimize the cost and achieve optimal network connectivity. A greedy set-cover algorithm is proposed for selecting intersections to deploy RSUs [7]. They formulated the problem of RSU deployment as the optimal selection of road intersections for RSUs. They focus on improving network connectivity and reducing the probability and time period of network partition with limited number of RSUs. The advantages of these schemes are that they maximize the number of road intersections to be covered and deploy RSUs in the places with high vehicle density, which maximizes the effect of RSU to transmit information in VANET. While the works are not applicable to the highways where the vehicle density is random.

In [8], the authors researched the trade-offs between the size of the gaps between RSUs and other system parameters. In [9], the authors aimed to the optimal deployment of RSUs on highways, which minimizes the end-to-end delay of information transmission from vehicle to RSUs. However, the schemes in [8, 9] just for a separate street. The uniform distribute is not the optimal strategy, as it does not consider the density of vehicles and the delay of information transmission.

A novel algorithm is also presented based on Voronoi graph [10]. Delay and loss of data packets are considered as two criteria for effectively deploy RSUs. The researchers in literature [11] introduce a new strategy to create abstraction of a map of a city area into a grid graph. Thereafter, they formulated the problem as a new optimization problem and showed its non-deterministic polynomial-time hardness (NP-hardness). To solve this problem, they proposed a new approximation algorithm. The time complexity of the algorithm satisfies the polynomial time. This method has two advantages: one is that it allows for the significant reduction in the number of RSUs required to cover a geographical area; another one is that it increases the logical coverage area of each RSU to improve the reliability of communication. While the disadvantage is that the highway is a pipeline. Vehicle distribution is linear. So we cannot abstract a map of vehicle network into a grid graph. It is not suitable to deploy RSUs by using graph algorithm.

An effective RSU deployment scheme is proposed [12]. The genetic algorithm was adopted to optimally calculate points for deploying RSUs starting from the initial candidate deployment points. Mahmoud, Ayman and Walid presented the traditional genetic algorithm based on RSUs deployment to calculate an approximate optimal solution [13]. But the process of obtaining the optimal value by genetic algorithm usually begins with the initial solution. And vehicles are randomly distributed in smart highway environment, which cannot provide initial location set for deployment of RSU.

Recently two greedy-based algorithms are proposed (called as Greedy2P3 and Greedy2P3E) and it is shown that the Greedy2P3E's approximation ratio is at least $1-(n-1/n)^2$ [14]. Then, by exploiting the properties of the one-dimensional RSU deployment (D1RD) problem, they proposed the optimal algorithm named OptGreDyn, which implies combining the greedy idea and dynamic programming. The joint placement by sleep scheduling of RSUs is proposed in the VANET environment [15]. They formulated an optimization problem capturing the behavior of a realistic scenario and proposed an energy efficient candidate location selection algorithm to jointly perform the placement and sleep scheduling of grid-connected solar powered RSUs. However, the RSU considered in this paper is the same as the vehicle node that is regardless of energy consumption. Therefore, it is not necessary to consider the sleep mechanism of RSUs.

To solve some of the above disadvantages on deploying RSUs, the strategy of an approximation algorithm to distribute RSUs in smart highway environment utilized in our proposed method, based on the goal to get the minimal number of deployed RSUs while guaranteeing the connectivity of the VANET within a given threshold. And the deployment of RSUs equidistantly is achieved. As a result, the threshold value M of RSUs corresponds to each vehicular network with N vehicles, and the connectivity probability increases slowly with the number of RSUs getting larger.

3. Design of RSU infrastructure

3.1 RSU deployment

3.1.1 Scheme of RSU deployment

The connectivity and coverage of the network are low if data is transmitted by vehicles on a highway. However, these network parameters can be improved using roadside node-assisted transmission.

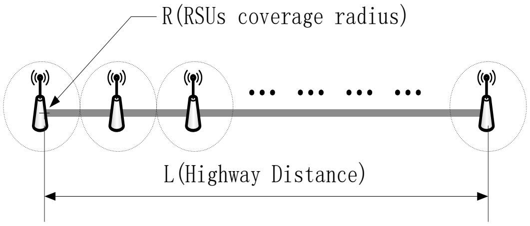

Figure 1. RSU deployment in extreme cases

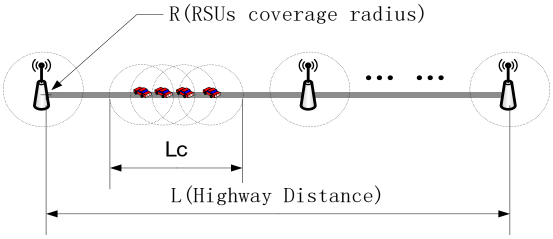

Figure 2. RSU deployment in general cases

Let us consider the number distribution of candidate RSU nodes to be as shown in Fig 1 in extreme cases. Next, let us assume that the total length of the highway is L, and the coverage radius of RSUs is R. If the network is fully connected, then the number of required candidate roadside nodes is defined as N=L/2R. Let us consider the deployment in general as shown in Fig 2. The communication time between two vehicles can be neglected here. In (1), the average cluster length of vehicles for two adjacent roadside nodes is L_c. The average velocity is E[V]. Assuming that the delay of an early warning message is τ, the distance between the two adjacent RSU nodes is;

$$L_u = L_c + E[V]\tau + 2R \tag{1}$$

Consequently, the number of RSUs required is;

$$N = L/L_c + E[V]\tau + 2R \tag{2}$$

The cost of deploying a large number of roadside nodes is extremely high, when L>>2R， L>>L_c， L>> E[V]τ.

3.1.2 RSU-assisted data transmission

The speed of a vehicle is faster on a highway than on a normal road. Consequently, it is difficult to establish long-lasting stable links between two moving vehicles, which leads to the incomplete transmission of data packets. In this paper, the static characteristics of roadside nodes are considered to solve the abovementioned problems. Let us suppose that the current speed is v, the communication radius of the vehicle is r, and the coverage range of RSUs is R. It is possible to establish stable links within t=2min{R, r}/v. In the scenario shown as Fig 3, the vehicles run on the road at the preset speed and follow the random distribution. Each vehicle consequently connects with the roadside nodes in two ways, one is directly connected with the roadside node, while another is connected with the roadside node through relay vehicles. Then each vehicle can transmit data packets to roadside nodes forward or backward by the means. Specifically, the transmission direction consistent with the driving direction of the vehicle is a forward transmission, otherwise, it is a backward transmission. Besides the maximum wireless transmission distance of all vehicle nodes is the same. Therefore, roadside nodes can be deployed as reliable transport layers in the two-tier data transmission architecture.

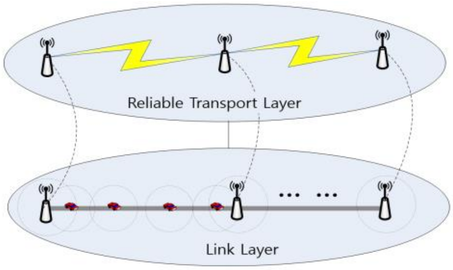

Figure 3. Two-tier data transmission Architecture

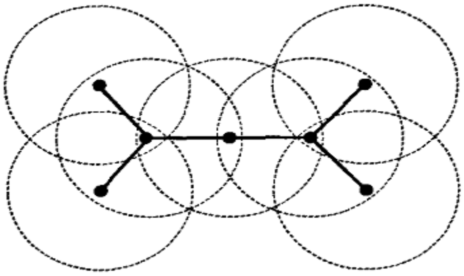

Figure 4. Unit disk graph in VANET

3.2 Problem definition

The purpose of deploying RSU is to ensure the connectivity within VANET. The problem to be solved in this paper is how to determine the deployment distance of RSU, Thereby, we propose an approximation algorithm to calculate the approximate optimal deployment distance d.

Definition 3-1. Let the location of the current node be the center of the circle, and the maximum transmission range of wireless communication be the radius. Let us assume that the maximum wireless transmission range of nodes is the same. Hence, the wireless transmission area of each node in the graph can be represented using a disk shape. If two nodes are in each other's transmission area, then these two nodes can communicate with each other. If the transmission radius of the node is normalized, then the transmission area of the node is a unit circle as shown in Fig 4. If two nodes can communicate with each other, then a link will be established in the two nodes. An edge will be adopted to represent the link between the two points in a related topology.

Definition 3-2: Let us consider that each RSU has a unique ID. Let function g: N->N denotes a connected topology of a RSU. If two RSUs with ID=x and ID=y are connected, only if g(x) = g(y). If all RSUs are wired, then the function $g_c(x) = 1$, for each RSU. Let x be the ID of the RSU. If RSU is not wired, then Let $g_u(x)$ be its connected topology and x be the ID of the RSU.

Definition 3-3: Let M represent a highway system. It contains all the properties of a highway such as having two-way lanes, the average density of vehicle b, the vehicle speed range within [v1, v2], and the maximum wireless transmission range R of vehicles.

Definition 3-4: Let Rg(.) denote a random event on a highway.

3.3 Approximation algorithm

Let the initial deployment distance be d_0. If the distance can satisfy the given conditions, when the RSU is deployed at this length and equidistance, the algorithm returns the value. Otherwise, the approximation algorithm decreases the deployment distance to $d_0(1-\theta)$. If the updated distance also cannot satisfy the given conditions, then the deployment distance is set to $d_0(1-\theta)^2$ and so on, until the given conditions are sufficed. For each deployment distance d, a sufficient number of freeway scenarios are randomly initialized for experiments, which mean the length of highway is fixed, and initial location of vehicle nodes is random. The simulated velocity range is [10, 30] m/s.

Algorithm 3-1 Approximation algorithm

```
Input: $d_0$: initial deployment distance;
           parameters $\theta \in (0,1)$;
Output: $d_{opt}$;
Start $d_0$, $i = 0$;
Let the RSUs interval distance be $d_i$ ;
Let $X_i = R_g(.)$, for i=1, 2, ..., n;
Let random events be n for connecting RSUs of the neighbor distance $d_i$ via executing Rg( . );
Calculate the count $S_i = \sum_{i=1}^{n} X_i$ of instances of successful transmissions;
$d_{i+1} = d_i(1-\theta)$ ;
Calculate the count $S_{i+1} = \sum_{i=1}^{n} X_i$ of instances of successful transmissions;
If $(S_{i+1} - S_i)/(S_i - S_{i-1}) < 1$;
$d_{opt} = d_i$;
Output: $d_{opt}$;
```

3.4 Algorithm analysis

3.4.1 Correctness analysis

The difference between the solution obtained by the proposed algorithm and the theoretically optimal solution has to be maintained within a reasonable range. In the randomized algorithm, for $i = 1, \ldots, n$, let X_i be independent random variables that take the value of unity with probability p_i and 0 otherwise. Let $X = \sum_{i=1}^{n} X_i$, and $\mu = E[x] = \sum_{i=1}^{N} p_i$. After determining the number of RSUs based on μ, the expectation of the deployment distance can be determined. Therefore, in (3) we should estimate the probability that X deviates from its expected distance;

$$P_r(X > pn + \varepsilon n), \text{ and } P_r(X < pn - \varepsilon n), \text{ where } p = \sum_{i=1}^{N} p_i / n \tag{3}$$

The Chernoff bound [16] is adopted to assess the effectiveness of the algorithm. The Chernoff bound uses the Markov inequality to constrain the sum of probability in the independent experiments. According to the Chernoff bound, let $X_1, \cdots, X_n$ be the independent events that obey the Poisson distribution. In (4), the probability is p_i when $x_i = 1$. Let $X = \sum_{i=1}^{n} X_i$, and $\mu = E[X]$.

$$P_r(X > (1+\delta)\mu) \le \left[\frac{e^{\delta}}{(1+\delta)^{(1+\delta)}}\right]^{\mu} \text{ and } P_r(X < (1-\delta)\mu) \le \left(\frac{e^{-\delta}}{(1-\delta)^{(1-\delta)}}\right)^{\mu} \text{ for any } \delta > 0 \tag{4}$$

According to the mathematical analysis, it is easy to obtain by (5);

$$\frac{e^{\delta}}{(1+\delta)^{(1+\delta)}} \le e^{-\delta^2/3} \quad \text{and} \quad \frac{e^{-\delta}}{(1-\delta)^{(1-\delta)}} \le e^{-\delta^2/2} \tag{5}$$

Therefore, we use the same technique to bound by (6);

$$P_r(X > pn + \varepsilon n) < e^{-\frac{1}{3}n\varepsilon^2} \text{and } P_r(X < pn - \varepsilon n) < e^{-\frac{1}{2}n\varepsilon^2} \tag{6}$$

This confirms that the achieved result is appropriate.

3.4.2 Approximation ratio analysis

In the present research, we perform the approximation ratio analysis similar to the analysis discussed in the study [17]. Hereinafter, $\mathrm{T_i}$ represents the approximation ratio. Let $\mathrm{T_i} = \mathrm{d_{opt}}/\mathrm{d_i}$, where d_{opt} is the optimal distance for deploying RSUs. $d_i = (1-\theta)^i d_0$, where θ is the parameter introduced for approximation accuracy, which controls the approximation between the solution obtained by the algorithm and the theoretically optimal solution. $(1-\theta)^i d_0$ is the approximation deployment distance of RSU that is returned by the approximation algorithm. Thereby, this inequality holds as $(1-\theta)^{i+1} d_0 < d_{opt} < (1-\theta)^i d_0$.

For each $d_i = (1-\theta)^i d_0$, the sufficient number of highway scenes are randomly initialized for the purpose of our experiments. The approximate ratio T_i satisfies $1 - \theta < T_i < 1$. For any $\varepsilon \in (0,1)$, $\frac{d_i - d_{opt}}{d_{opt}} < \varepsilon$, then $\frac{(1-\theta)^i d_0 - d_{opt}}{d_{opt}} < \varepsilon$. We can obtain by (7);

$$\theta > 1 - e^{\frac{1}{i} ln \frac{(1+\varepsilon) d_{opt}}{d_0}} \tag{7}$$

by mathematical analysis. As $\frac{d_i - d_{opt}}{d_{opt}} > 0$, we can obtain by (8);

$$\theta < 1 - e^{\frac{1}{i} ln \frac{d_{opt}}{d_0}} \tag{8}$$

therefore, θ is within the range as (9);

$$1 - e^{\frac{1}{i} ln \frac{(1+\varepsilon)d_{opt}}{d_0}} < \theta < 1 - e^{\frac{1}{i} ln \frac{d_{opt}}{d_0}} \tag{9}$$

4. Performance analysis

4.1 Experimental parameters

In this simulation experiment, the length of the highway is considered to be 40 km. Vehicles travel eastward or westward on the corresponding lanes. The initial location of vehicle nodes is random. The maximum wireless transmission distance of vehicle nodes is 250 m. The number of vehicle nodes vn=100 represents the average traffic flow on the highway. The number of vehicle nodes vn=50 represents the sparse traffic flow on the highway. vRSU represents the number of RSUs. R represents the maximum wireless transmission range of the node. RSUs are deployed at the same distance on the highway. The experimental parameters are presented in Table 1.

Table 1. Main parameters

Simulation Parameter	Value
Topology Size	40km
Number of Nodes	50; 100
The max transmission Range	250
Bandwidth	2Mbps
The traffic type	CBR
The number of experiments	10

The direct connectivity probability represents the ratio of the number of vehicles connected to RSU to the total number of nodes. The indirect connectivity probability represents the ratio of the number of nodes connected to RSU by relaying other nodes to the total number of nodes. The total connectivity probability is the sum of the two abovementioned probability values.

4.2 Simulation results and analysis

The total connectivity probability increases with the number of deployed RSUs as shown in Fig 5 and Fig 6 (Where, p1 represents the direct connected probability vs the number of RSU; p2 represents the indirect connected probability vs the number of RSU; p3 represents the total connected probability vs the number of RSU). The direct connectivity probability increases almost linearly with the number of deployed RSUs, and the indirect one demonstrates the non-linear growth. The probability of direct connection is much higher than that of indirect connection. This indicates that the deployment of RSUs can greatly increase the connectivity on a highway in general. When vn is 50, and the number of deployed RSUs is 60, the indirect connectivity probability reaches the maximum. The probability decreases with increasing the number of deployed RSUs. This is due to the fact that with the number of RSUs increasing, more and more vehicles can be directly connected to RSU. When vRSU=60, the total connectivity probability increases slowly with the number of RSUs increasing. In this case, vRSU=60 is considered to be the approximate optimal solution. Similarly, according to the data presented in Fig 6, vRSU=60 is the approximate optimal solution with vn=100.

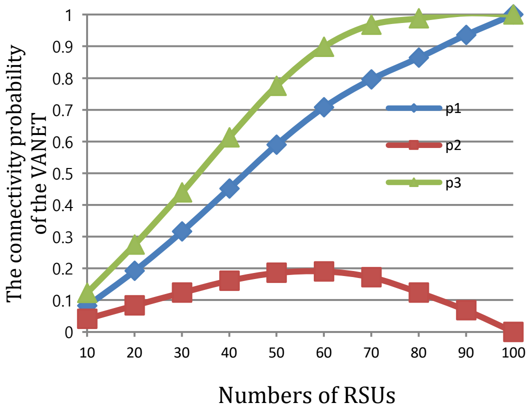

Figure 5. Connectivity probability of VANET (vn=50)

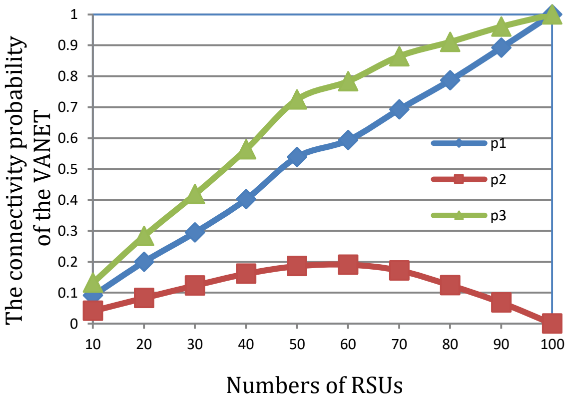

Figure 6. Connectivity probability of VANET(vn=100)

5. Conclusion

We propose an RSU deployment scheme for a highway scenario in a vehicular network. For each highway, we also present an approximation algorithm to estimate the number of required RSUs to obtain the approximate optimal solution. In the simulation experiment, the connection probability between vehicle nodes and RSUs was tested to determine the advantages and disadvantages of the proposed deployment scheme. The simulation results indicated that there is a threshold value M of the number of required RSUs corresponding to each vehicular network with N vehicles. Subsequently, the connectivity probability was observed to gradually increase with the increase in the number of RSUs.

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