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Zhenyu Wang[1], Jun Zheng[1], Yuying Wu[1], and Nathalie Mitton[2]

[1]National Mobile Communications Research Laboratory
Southeast University
2 Si Pai Lou, Nanjing, Jiangsu 210096, China
[2]Inria Lille – Nord Europe,
40 Avenue Halley, 59650 Villeneuve D'ASCQ, France
Email: junzheng@seu.edu.cn

***Abstract*—This paper studies the RSU deployment problem in a 2-D urban or suburban road scenario of a vehicular ad hoc network (VANET). To optimize RSU deployment, we introduce the notion of centrality in a social network to RSU deployment, and use it to measure the importance of an RSU position candidate in RSU deployment. Based on the notion of centrality, we propose a centrality-based RSU deployment approach and formulate the RSU deployment problem as a linear programing problem with the objective to maximize the total centrality of all position candidates selected for RSU deployment under the constraint of a given deployment budget. To solve the formulated problem, we analogize the problem to a 0-1 Knapsack problem and thus employ a 0-1 Knapsack algorithm to solve the problem. In the analogy, the budget in the RSU deployment problem is analogous to the bag's capacity in the Knapsack problem, the cost of deploying an RSU is analogous to an item's weight, and the centrality of a position candidate is analogous to an item's value. Simulation results show that the proposed centrality-based deployment approach can effectively improve the efficiency of the RSU deployment in terms of the coverage time ratio as compared to a random deployment approach.**

***Keywords*-centrality; deployment, roadside unit; RSU; VANET; vehicular ad hoc network**

I. INTRODUCTION

Roadside Units (RSUs) are an important component of vehicular ad hoc networks (VANETs) [1][2]. In a VANET, RSUs are deployed at intersections or some points along a road to help improve network connectivity, data delivery, and thus network services to vehicles. Therefore, RSU deployment has a big impact on the network performance and becomes an important issue in the design of a VANET.

In general, RSU deployment is costly. To achieve a good tradeoff between deployment cost and network performance, it is expected to optimize the deployment of RSUs in a VANET. To address this challenge, considerable research work has been conducted on the optimization of RSU deployment for VANETs [3-11]. However, existing RSU deployment strategies exhibit their own limitations. For example, some of them only consider the RSU deployment in 1-D road scenarios [3-5]; some of them only consider the same cost of deploying RSUs in different scenarios [3][6][11]; some of them require many parameters which may change over time, such as the density of traffic [4][7]. To improve the efficiency of RSU deployment, it is necessary to further study the RSU deployment problem and explore more effective RSU deployment approaches.

In this paper, we focus on the RSU deployment problem in a 2-D urban or suburban road scenario. To optimize the RSU deployment, we introduce the notion of centrality in a social network to RSU deployment, and use it to measure the importance of an RSU position candidate in RSU deployment. Based on the notion of centrality, we propose a centrality-based RSU deployment approach and formulate the RSU deployment problem as a linear programing problem with the objective to maximize the total centrality of all position candidates selected for RSU deployment under the constraint of a given deployment budget. To solve the formulated problem, we analogize the problem to a 0-1 Knapsack problem [12] and thus employ a 0-1 Knapsack algorithm to solve the problem. In the analogy, the budget in the RSU deployment problem is analogous to the bag's capacity in the Knapsack problem, the cost of deploying an RSU is analogous to an item's weight, and the centrality of a position candidate is analogous to an item's value. Simulation results show that the proposed centrality-based deployment approach can effectively improve the efficiency of RSU deployment in terms of the coverage time ratio as compared to a random deployment approach.

The remainder of this paper is organized as follows. Section II reviews related work on the RSU deployment problem in VANETs. Section III formulates the RSU deployment problem considered in this paper and presents the proposed centrality-based RSU deployment approach. Section IV evaluates the performance of the proposed deployment approach through simulation results. Section V concludes this paper.

II. RELATED WORK

RSU deployment has been widely studied in literature [3-11]. Some studies only consider the RSU deployment problem in 1-D road scenarios such as highways. For example, Rashidi et al. studied RSU Placement for floating car data collection in a highway scenario in [3]. The trade-offs between the RSU interval and other system parameters were studied and a heuristic algorithm was proposed to calculate the interval between RSUs. In [4], Aslam and Zou proposed an optimal placement of RSUs along highways with the goal of minimizing the average time taken for a vehicle to report an event of interest to a nearby RSU with a limited number of RSUs. Not only the cost but also the energy consumption of RSUs was

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considered in the deployment. In [5], Tao et al. proposed an RSU deployment scheme with power control for highway message propagation in VANETs and aimed to minimize the energy consumption of RSUs and maximize the network performance.

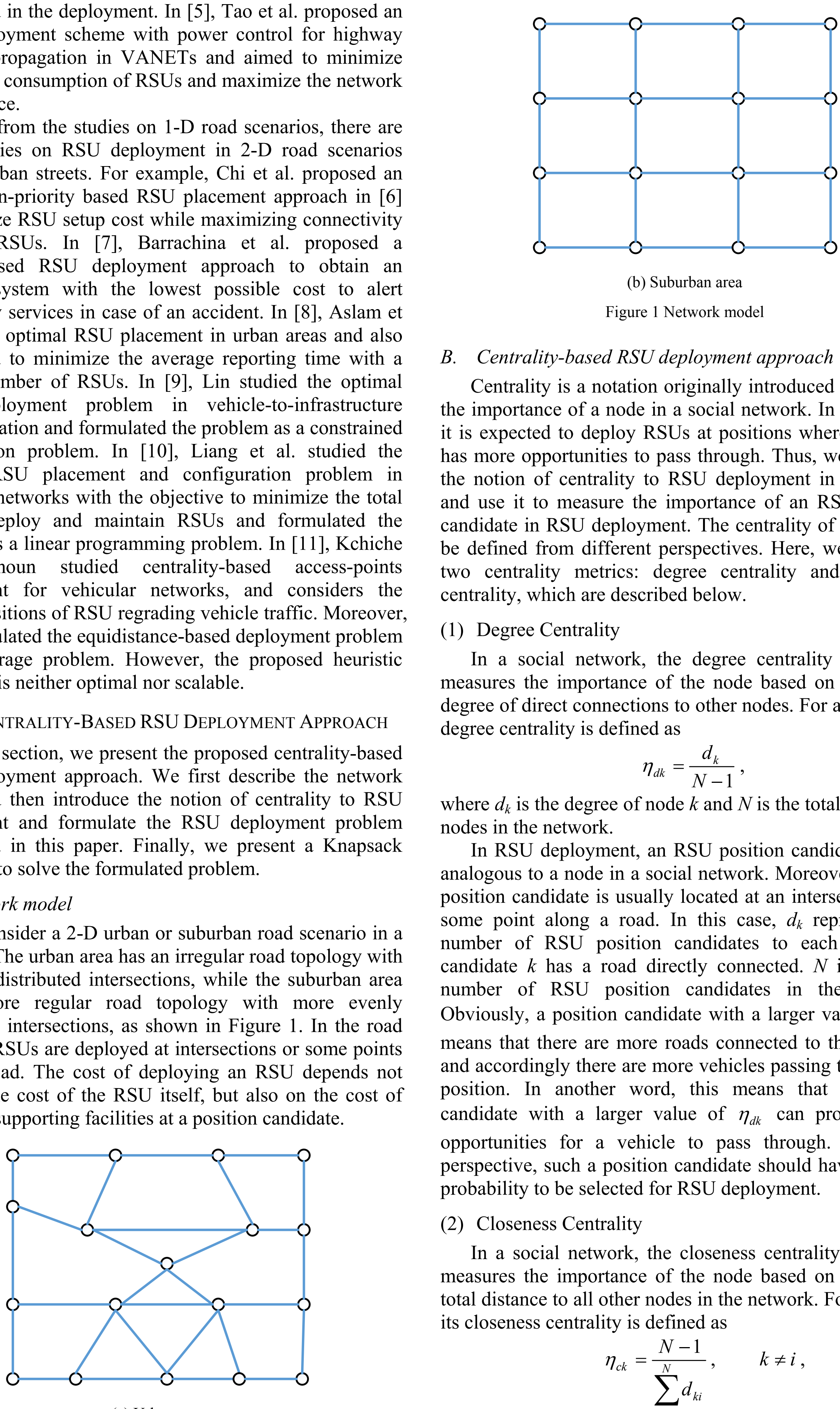
Apart from the studies on 1-D road scenarios, there are some studies on RSU deployment in 2-D road scenarios such as urban streets. For example, Chi et al. proposed an intersection-priority based RSU placement approach in [6] to minimize RSU setup cost while maximizing connectivity between RSUs. In [7], Barrachina et al. proposed a density-based RSU deployment approach to obtain an efficient system with the lowest possible cost to alert emergency services in case of an accident. In [8], Aslam et al. studied optimal RSU placement in urban areas and also considered to minimize the average reporting time with a limited number of RSUs. In [9], Lin studied the optimal RSU deployment problem in vehicle-to-infrastructure communication and formulated the problem as a constrained optimization problem. In [10], Liang et al. studied the optimal RSU placement and configuration problem in vehicular networks with the objective to minimize the total cost to deploy and maintain RSUs and formulated the problem as a linear programming problem. In [11], Kchiche and Kamoun studied centrality-based access-points deployment for vehicular networks, and considers the central positions of RSU regrading vehicle traffic. Moreover, they formulated the equidistance-based deployment problem as a coverage problem. However, the proposed heuristic algorithm is neither optimal nor scalable.

III. Centrality-Based RSU Deployment Approach

In this section, we present the proposed centrality-based RSU deployment approach. We first describe the network model and then introduce the notion of centrality to RSU deployment and formulate the RSU deployment problem considered in this paper. Finally, we present a Knapsack algorithm to solve the formulated problem.

A. *Network model*

We consider a 2-D urban or suburban road scenario in a VANET. The urban area has an irregular road topology with unevenly distributed intersections, while the suburban area has a more regular road topology with more evenly distributed intersections, as shown in Figure 1. In the road scenario, RSUs are deployed at intersections or some points along a road. The cost of deploying an RSU depends not only on the cost of the RSU itself, but also on the cost of installing supporting facilities at a position candidate.



(a) Urban area

(b) Suburban area

Figure 1 Network model

B. *Centrality-based RSU deployment approach*

Centrality is a notation originally introduced to measure the importance of a node in a social network. In a VANET, it is expected to deploy RSUs at positions where a vehicle has more opportunities to pass through. Thus, we introduce the notion of centrality to RSU deployment in a VANET and use it to measure the importance of an RSU position candidate in RSU deployment. The centrality of a node can be defined from different perspectives. Here, we introduce two centrality metrics: degree centrality and closeness centrality, which are described below.

(1) Degree Centrality

In a social network, the degree centrality of a node measures the importance of the node based on the node's degree of direct connections to other nodes. For a node *k*, its degree centrality is defined as

$$\eta_{dk} = \frac{d_k}{N-1}, \tag{1}$$

where d_k is the degree of node *k* and *N* is the total number of nodes in the network.

In RSU deployment, an RSU position candidate can be analogous to a node in a social network. Moreover, an RSU position candidate is usually located at an intersection or at some point along a road. In this case, d_k represents the number of RSU position candidates to each of which candidate *k* has a road directly connected. *N* is the total number of RSU position candidates in the network. Obviously, a position candidate with a larger value of η_{dk} means that there are more roads connected to this position and accordingly there are more vehicles passing through the position. In another word, this means that a position candidate with a larger value of η_{dk} can provide more opportunities for a vehicle to pass through. From this perspective, such a position candidate should have a higher probability to be selected for RSU deployment.

(2) Closeness Centrality

In a social network, the closeness centrality of a node measures the importance of the node based on the node's total distance to all other nodes in the network. For a node *k*, its closeness centrality is defined as

$$\eta_{ck} = \frac{N-1}{\sum_{i=1}^{N} d_{ki}}, \qquad k \neq i, \tag{2}$$

where d_{ki} is the geodesic distance between node k and node i, and N is the total number of nodes in the network.

In RSU deployment, d_{ki} represents the shortest path between position candidate k and position candidate i. A larger value of η_{ck} means a smaller total shortest path distance from candidate k to all other candidates. This means that a position candidate with a larger value of η_{ck} allows a vehicle to enter its coverage more quickly and thus can provide better quality of service to the vehicle. From this perspective, such a position candidate should also have a higher probability to be selected for RSU deployment.

C. Selection of RSU position candidates

In an urban or suburban area, RSUs can usually be deployed at intersections to provide services to passing vehicles. However, when a road segment is long and the coverage of RSUs at intersections cannot cover the road segment, an RSU can be deployed at some point along the road segment to avoid interruptive connections and improve the quality of service to vehicles.

Assume that the coverage of an RSU is R_u and the length of a road segment between two adjacent intersections is L. The selection of RSU candidates is performed according to the following rules:

a) For a road segment with $L \leq 2R_u$, the intersections of the road segment are selected as position candidates. The number of position candidates along the road segment is two.

b) For a road segment with $L > 2R_u$, the intersections of the road segment are selected as the position candidates. Meanwhile, a certain points along the road segment are also selected as position candidates, which are uniformly distributed along the road segment. The number of position candidates along the road segment is given by $\lceil (L-2R_u)/2R_u \rceil$.

D. Problem formulation

Consider a two-dimensional urban or suburban road scenario with a set of N RSU position candidates, as shown in Figure 1. Let c_k denote the deploying cost of RSU position candidate k; η_k denote the centrality of position candidate k, k=1, 2, …, N, which can be calculated based on either Eq. (1) or Eq. (2); and $X_k = \{0,1\}$ denote a boolean variable indicating whether a position candidate is selected for RSU deployment, which is defined as

$$X_k = \begin{cases} 1 & \text{candidate } k \text{ is selected} \\ 0 & \text{candidate } k \text{ is not selected} \end{cases}, \quad k = 1,2,...,N .$$

Moreover, assume that the RSU deployment budget for this road area is B.

Given the RSU deployment budget and the above definitions, the RSU deployment problem considered in this paper can be formulated into a linear programing problem with the objective to maximize the RSU coverage, i.e., to find a subset of RSU position candidates or determine $X_k (k = 1,2,...,N)$ so that the total centrality of the candidates contained in the subset is maximized, i.e.,

$$\max \sum_{k=1}^{N} \eta_k X_k , \tag{5}$$

subject to

$$\sum_{k=1}^{N} c_k X_k \leq B , \tag{6}$$

where η_k can be either η_{dk} or η_{ck}.

It is found that the above formulated RSU deployment problem can be analogous to the classical 0-1 Knapsack problem [12], which can be solved by using a Knapsack algorithm.

E. RSU deployment algorithm

Next we present the Knapsack algorithm to solve the problem.

(1) Analogous to the 0-1 Knapsack problem

The 0-1 Knapsack problem is a classical combinatorial optimization problem. Suppose that there is a bag which can hold a total weight W and there are n kinds of items. Each item has a weight w_k and a value v_k (k= 1, 2, …, n). Thus, the 0-1 Knapsack problem is how to find a subset of these items to put into the bag so that the total value of items in the bag is maximized. Obviously, the formulated RSU deployment problem can be analogous to the 0-1 Knapsack problem if budget B is analogous to the bag's capacity W, cost c_k is analogous to each item's weight w_k, and centrality η_k is analogous to each item's value v_k. Therefore, we can use the Knapsack algorithm to solve the formulated RSU deployment problem.

(2) Knapsack algorithm for RUS deployment

The Knapsack algorithm is a dynamic programming algorithm. According to the formulation of the RSU deployment problem, a solution to the problem is a subset of all N position candidates, whose total centrality is maximized with their total budget constrained by B. To find the solution to the problem, define m(i,b) as the total centrality of a subsolution to candidates i, i+1, . . . , N given budget b. By the nature of the optimal sub-structure of the 0-1 knapsack problem, we can establish an iteration relation of m(i,b), i.e,

$$m(i,b) = \begin{cases} \max\{m(i+1,b), m(i+1,b-c_i)+\eta_i\} & b \geq c_i \\ m(i+1,b) & 0 \leq b < c_i \end{cases}, \tag{7}$$

$$m(N,b) = \begin{cases} \eta_N & b \geq c_N \\ 0 & 0 \leq b < c_N \end{cases}, \tag{8}$$

$$i = 1,2,...,N$$

Obviously, the value of the optimal solution is m(1,B), which can be calculated using Eq. (7) through iterations, starting from m(N,b) with Eq. (8). After a sequence of iterations, we can obtain a table of m(i,b), which can be used to deduce the solution to the problem, i.e., a subset of position candidates that are selected for RSU deployment. The deduction process starts at m(1,B) and traces backwards where the optimal solution was obtained. If m(i,b) = m(i+1,b), candidate i is not part of the solution, and then continue tracing with m(i+1, b). Otherwise, candidate i is part of the solution, and then continue tracing with m(i+1, b-c_i). The pseudo-code of the algorithm is given below.

Algorithm : *RSU deployment based on centrality* (C, N, B)

Input : *the cost of each RSU position candidate* $C = \{c_1, \ldots, c_N\}$;
  the number of RSU position candidates N;
  the budget of deployment B;
Output : *a set of RSU deployment positions* X;
Initialization : *calculate centrality of each RSU position candidate*
$\eta = \{\eta_1, \ldots, \eta_N\}$;
for $b = 0$ *to* B *do*
  if $0 \le b < c_N$ *then*
    $m(N, b) = 0$
  else
    $m(N, b) = \eta_N$
for $i = N-1$ *to* 1 *do*
  for $b = 0$ *to* B *do*
    if $b \ge c_i$ *then*
      $m(i, b) = \max\{m(i+1, b), m(i+1, b-c_i) + \eta_i\}$
    else
      $m(i, b) = m(i+1, b)$
for $i = 1$ *to* $N-1$ *do*
  if $m(i, B) == m(i+1, B)$ *then*
    $X[i] = 0$
  else
    $X[i] = 1$
    $B = B - c_i$
$X[N] = m(N, B)\,?\,1 : 0$
Return X

IV. Simulation Results

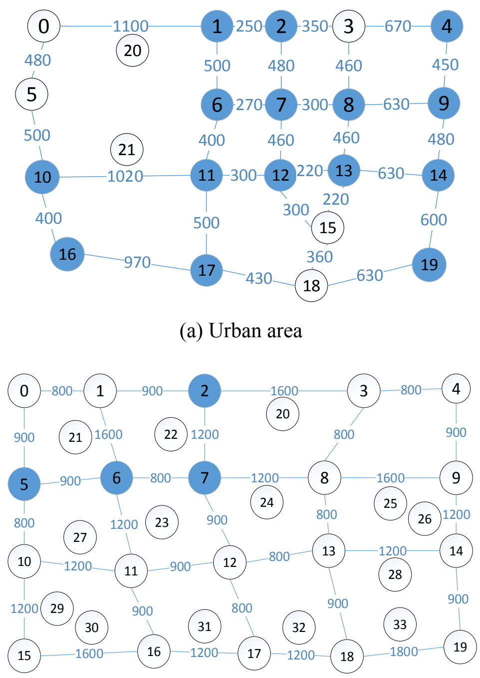
In this section, we evaluate the performance of the proposed centrality based RSU deployment approach (CDA) through simulation results. For this purpose, we developed a simulator using C++ programing language and conducted a series of experiments. Most existing RSU deployment approaches are based on some statistical parameters of a road scenario, such as traffic density, while our proposed approach can find a deployment solution without using any statistical parameters of the road scenario. Thus, it is hard to find a suitable existing RSU deployment approach to compare with in evaluation. Instead, we compare CDA with a random deployment approach (RDA). For CDA, we consider two metrics of centrality: degree centrality and closeness centrality, and use CDA-DC and CDA-CC to represent, respectively.

In the simulation experiments, we considered two road scenarios or topologies as shown in Figure 2. The number on each road segment represents the length of the road segment. A circle represents an RSU position candidate. A shaded circle represents a position candidate at an intersection with traffic light. A non-shaded circle represents a position candidate at an intersection without traffic light or at some point along a road segment. The RSU position candidates are determined based on the road topology and the selection rules given in Section III.C. Moreover, we introduce the coverage time ratio as a performance metric to evaluate the efficiency of RSU deployment, which is defined as the ratio of the amount of time a vehicle is covered by RSUs to the total amount of time the vehicle moves in the road area. Obviously, a larger value of the coverage time ratio means that a vehicle has a larger probability to be covered and thus served by RSUs during its movement in the area. Moreover, we assume that there are M vehicles moving in the road area and each vehicle moves at a constant speed in a free-flow state.

We consider different deployment cost at different position candidates. The parameters used in the simulation experiments are summarized in Table I.

TABLE I. Simulation Parameters

Parameter	Value
RSU coverage R_u	500m
Vehicle speed v	16m/s
Cost of deploying an RSU at an intersection with traffic light c_a	15000¥
Cost of deploying an RSU at an intersection without traffic light c_b	20000¥
Cost of deploying an RSU on a road segment with traffic light c_c	17500¥
Cost of deploying an RSU on a road segment without traffic light c_d	20000¥



(a) Urban area

(b) Suburban area

Figure 2 Road topology

Figure 3 shows the coverage time ratio with CDA-DC, CDA-CC, and RDA, respectively, for different number of vehicles in the urban area. It is seen that the coverage time ratios with both CDA-DC and CDA-CC are significantly larger than that with RDA. This means RSU deployment with CDA can provide better RSU services to vehicles than that with RDA. On the other hand, it is seen that the coverage time ratio decreases with the number of vehicles increasing. This is because with the increase of the number of vehicles, more vehicles may move on road segments without the coverage of RSUs, making the coverage time ratio decrease.

Figure 4 shows the coverage time ratio with CDA-DC, CDA-CC, and RDA, respectively, for different deployment budgets in the urban area, when the number of vehicles M is 20. It is also seen that the coverage time ratios with both CDA-DC and CDA-CC are significantly larger than that with RDA. The coverage time ratio increases with the increase of the budget. Moreover, with the increase of the budget, the coverage time ratio with RDA tends to approach that with CDA. This is because in this case both CDA and RDA tend to deploy RSUs at all position candidates, which cover the whole area.

Figure 5 shows the coverage time ratio with CDA-DC, CDA-CC, and RDA, respectively, for different number of vehicles in the suburban area. Similarly, it is seen that the coverage time ratios with both CDA-DC and CDA-CC are significantly larger than that with RDA. This means RSU deployment with CDA can provide better RSU services to vehicles than that with RDA.

Figure 6 shows the coverage time ratio with CDA-DC, CDA-CC, and RDA, respectively, for different deployment budgets in the suburban area. It is also seen that the coverage time ratios with both CDA-DC and CDA-CC are significantly larger than that with RDA. The coverage time ratio increases with the increase of the budget. Moreover, with the increase of the budget, the coverage time ratio with RDA tends to approach that with CDA.

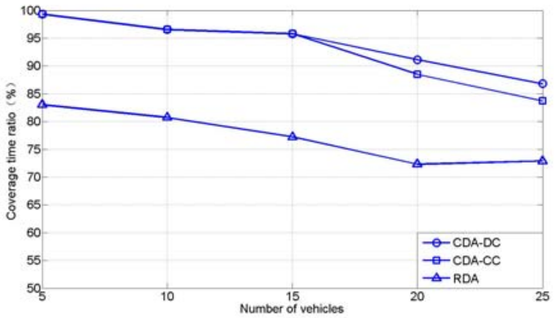


Figure 3 Coverage time ratio vs number of vehicles (*B*=200000¥)

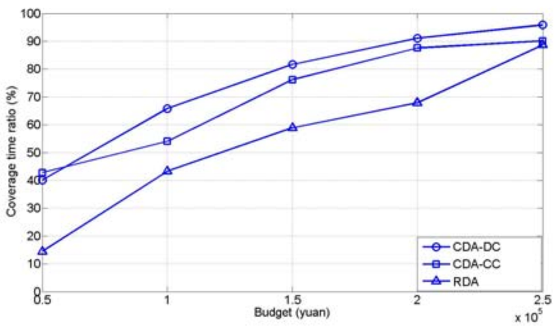


Figure 4 Coverage time ratio vs deployment budget (*M*=20)

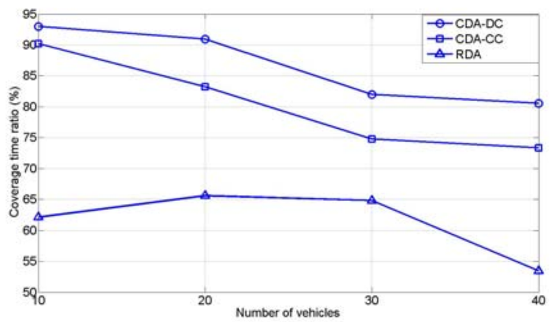


Figure 5 Coverage time ratio vs number of vehicles (*B*=300000¥)

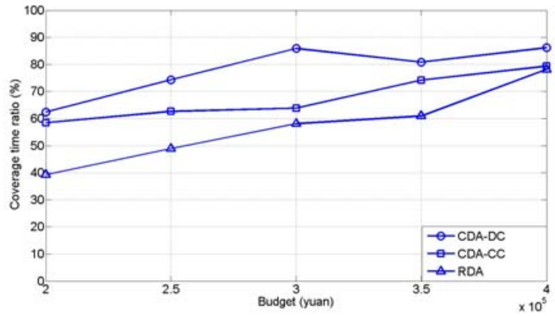


Figure 6 Coverage time ratio vs deployment budget (*M*=30)

V. CONCLUSIONS

In this paper, we introduced the notion of centrality in a social network to RSU deployment, and proposed a centrality-based RSU deployment approach for a 2-D urban or suburban road scenario. The centrality-based RSU deployment problem was formulated as a linear programing problem with the objective to maximize the total centrality of all position candidates selected for RSU deployment under the constraint of a given deployment budget. The formulated problem is analogous to a 0-1 Knapsack problem and can be solved by employing a 0-1 Knapsack algorithm. Simulation results show that the proposed centrality-based deployment approach can effectively improve the efficiency of RSU deployment in terms of the coverage time ratio as compared to a random deployment approach.

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