Hybrid Roadside Devices Placement for Advertisement Disseminations in Vehicular CPS

Junshan Cui[1,2], Peng Li[1,2](✉), Dongdong Yue[1,2], Yu Jin[1,2], Yu Liu[1,2], and Qin Liu[3]

[1] College of Computer Science and Technology, Wuhan University of Science and Technology, Hubei 430065, China
lipeng@wust.edu.cn

[2] Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Hubei 430065, China

[3] School of Computer, Wuhan University, Hubei 430074, China

Abstract. There are two types of roadside devices for advertisement dissemination in the Vehicular Cyber-Physical Systems (VCPS), one is roadside units (RSUs) and the other is roadside access points (RAPs). The placement cost of RSUs is lower than RAPs. However, the coverage of RSUs is limited. In this paper, we investigate the hybrid roadside device placement problem in the Vehicular Cyber-Physical Systems (VCPS). Given the budget constraint and the distribution of traffic conditions, our goal is to optimize the deployment of the hybrid roadside device for the merchants to maximize their benefits from advertisement dissemination. With the purpose of all advertisement can be effectively served, we propose a corresponding hybrid greedy placement algorithm. Our algorithm not only obtains the more benefits, but also consider the placement cost. Finally, we evaluate the performance of our proposed algorithm. Extensive simulations show that the performance of our proposed algorithm is superior to the other algorithms.

Keywords: Vehicular Cyber-Physical Systems · Roadside device placement · Advertisement dissemination

1 Introduction

With the development of wireless networks and vehicular ad hoc networks, there are more and more advertisement dissemination applications in Vehicular Cyber-Physical Systems(VCPS). The application of roadside advertisement dissemination in VCPS generally involves three elements: the drivers in the vehicles, roadside units, and merchants. By advertising to drivers in the vehicle, merchant

P. Li—This work is partially supported by the NSF of China (61502359, 61572370, 61303117), the National Students' Innovative Entrepreneurship Training Program (201510488016), and the Wuhan University of Science and Technology Innovative Entrepreneurship Training Program (15ZRA093, 15ZRC100).

Q. Chen et al. (Eds.): ChinaCom 2016, Part II, LNICST 210, pp. 486–495, 2018.
DOI: 10.1007/978-3-319-66628-0_46

attracts so as much as possible customers into the store shopping. However, due to the uneven distribution of merchants geographic location, different types of roadside units may have different profits in different locations. Considering how to ensure that all advertisements can be served timely and effectively, we also need to guarantee the expected merchants benefit. Eventually, it becomes especially important to give a scenario of roadside device placement.

In this paper, we investigate hybrid roadside devices placement, which applies in roadside advertising to maximize the benefit of merchants. The placement problem is correlative to multiple types of roadside device. There are two types of roadside devices for advertisement dissemination in the Vehicular Cyber-Physical Systems (VCPS), one is roadside units (RSUs) and the other is roadside access points (RAPs). As shown in Fig. 1, RAPs have following characteristics: wide coverage, large placement cost and high bandwidth. However, RSUs have features like small coverage range and low placement cost and low bandwidth. Traditional placement strategies only consider using a single type device, such as RAPs or RSUs. Therefore, it will cause the waste of resource inevitably. Thus, the hybrid deployment of multiple types of resource becomes more important. It not only concerns to the maximization of merchants benefits, but also saves the cost of deployment.

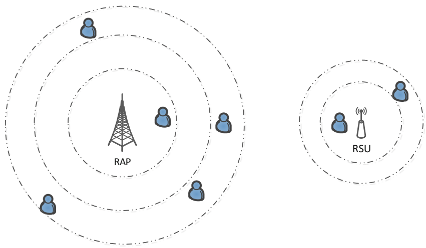


Fig. 1. RAP/RSUs schematic coverage.

Given a budget of deployment and the distribution of traffic flows, our goal is to determine how to deploy hybrid roadside device for the maximization of merchants benefits. In addition to the benefit, all the merchant must be ensure that it can be covered by at least one roadside device. It is a challenging issue in vehicular ad hoc networks. First of all, we consider how to choose an optimal candidate site to place a roadside device, which is proved that the problem is NP-complete. Moreover, we consider different types of roadside devices, that for each candidate site we need to decide which type of roadside devices we should choose, which is more complicated than the placement of the same type roadside devices. Therefore, the main contributions of this paper are summarized as follows:

– We consider the hybrid placement problem for advertising applications. In order to maximize the merchant benefits, we should consider how to place

the roadside device efficiently. We conduct the system model and give the formulation of the hybrid placement problem.
– Base on the problem formulation, we propose a hybrid roadside devices placement algorithm, which greedily deploy the roadside device to maximize the potential benefits.
– We conduct an extensive simulations to evaluate the performances of the proposed algorithm. Simulation results show that the performance of our proposed algorithm is superior to the other algorithms.

The remainder of this paper is organized as follows: Sect. 2 is the presentation of related work. Section 3 introduces the system model. In Sect. 4, we describe the proposed algorithm and give concrete solutions for Manhattan grid system. Section 5 includes the experimental results and analysis. Finally, we conclude paper in Sect. 6.

2 Related Work

In recent years, the application of advertisement dissemination becomes a novel and anticipated topic [1,2]. Li *et al.* [1] considered how to allocate bandwidth and schedule advertisement with existing roadside devices. And there are also many other studies about advertisement dissemination application with prefixed roadside devices. The work in [2] studied how to place roadside units for advertisement dissemination applications.

Nowadays, there are some work on node placement problem [3–8]. Yan *et al.* [3] investigated access point placement problem for data dissemination. Li *et al.* [4] studied two types roadside units placement problem, and proposed several algorithms to solve the problem. Reis *et al.* [5] studied the roadside units placement problem in the highway environment and propose the method to maximize the network performance. Ke *et al.* [6] investigated the critical-square-grid coverage problem in wireless sensor networks. Silva *et al.* [7] presented an algorithm for deployment of roadside units based on partial mobility information. Zhang *et al.* [8] developed an AP placement algorithm based on theoretical results to deploy the minimal number of roadside APs with QoS guarantees.

In hybrid node placement problem, Li *et al.* [9] considered two types roadside units and studied the delay-bounded minimal cost roadside units placement problem in vehicular ad hoc networks, and Lin and Deng [10] investigated the roadside units and sensors placement problem, and proposed a center particle swarm optimization approach to solve this NP-completed problem. However, none of them considered how to deploy hybrid roadside devices for advertisement dissemination.

3 System Model and Problem Formulation

3.1 System Model

In the system, there are n merchants (denoted by $S = \{s_i | i = 1, 2, ..., n\}$) and each of them contains m advertisements (denoted by $A = \{a_{i,j} | j = 1, 2, ..., m\}$), and each of advertisements has its corresponding size (denoted by $size_{i,j}$). For each advertisement, it has different attractive ratio (denoted by $att_{i,j}$), as well as the potential benefit $utl_{i,j}$. There are two types of roadside device (RAPs and RSUs). We assume that the bandwidth of RAPs is larger than RSUs', the transmission coverage of RAPs is larger than RSUs', and the placement cost of RAPs is larger than RSUs'. We assume that the distribution of traffic flow is known as a priori, vehicular users will take a detour to shopping or back home directly after receiving advertisements from roadside devices. We denote T as the set of traffic flow in the system, and $t_{x,y}$ corresponds to a traffic flow from intersection x to intersection y. Also, $|T|$ denotes the number of traffic flow. We denote the detour distance as $d_{x,y,i}$, which represents the vertical distance from the traffic flow $t_{x,y}$ to the merchant s_i.

We define vehicular users' detour probability as $f(att_{i,j}, d_{x,y,i})$, which means the probability that the vehicular users in traffic follow $t_{x,y}$ would take a detour to go shopping after receiving the *j-th* advertisement distributed by *i-th* merchants. Obviously, the vehicular users' detour probability has a positive correlation with advertisements attraction $att_{i,j}$, and it is related with the detour distance $d_{x,y,i}$ negatively. So we use a benefit function to describe the vehicular users' detour probability $f(att_{i,j}, d_{x,y,i})$ as follows:

$$f(att_{i,j}, d_{x,y,i}) = \begin{cases} att_{i,j} \times (1 - \frac{d_{x,y,i}}{D}), & d < D \\ 0, & d \geq D \end{cases} \tag{1}$$

where D is a threshold value which will be detailed later. According to real-world experience, merchants in some places are distributed densely, and they are usually located in relatively prosperous regions where the number of advertisements is large. However, there always exists some suburbs where the merchants distribution is relatively sparse, and the amount of advertisements is also small. So we consider a device (RAP or RSU) only broadcasting advertisements in the nearby area. Because the bandwidth of each roadside device is limited, and the number of advertisements that can be served in a certain period is also limited, so an appropriate device placement strategy can not only ensure adequate coverage range but also the efficiency of receiving advertisement. Therefore, we assume that all the roadside devices are deployed at intersections, and the number of intersections is q. Then, the set of these intersections is defined as $V = \{v_k | k = 0, 1, ..., q-1\}$. We denote $d_{x,y,k}$ as the distance from the intersection v_k to traffic flow $t_{x,y}$, which equals to the minimum distance between the intersection point and any point on the traffic flow. If the coverage range of roadside device is less than the distance of road segment, we also consider that the whole road segment is covered by the deployed roadside device. This assumption is acceptable, because the vehicles eventually go through the whole road segment after receiving the advertisements in the range of deployed roadside device.

We denote R_p and R_u as the transmission range of a RAP and a RSU, respectively. Similarly, we denote C_p and C_u as the cost of a RAP and a RSU for deployment. Then, the traffic flow coverage set of a RAP and a RSU, denoted by $T^{k,p}$ and $T^{k,u}$ can be expressed respectively as:

$$\begin{cases} T^{k,p} = \{t_{x,y} | d_{x,y,k} < R_p\} \\ T^{k,u} = \{t_{x,y} | d_{x,y,k} < R_u\} \end{cases} \tag{2}$$

We take Fig. 2 for example, the graph contains nine intersections, which labeled from #0 to #8. Each grid line represents a known traffic flow $t_{x,y}$. The graph also has 12 traffic flows, such as $t_{0,1}$, $t_{1,2}$, ..., etc. $t_{x,y}$ corresponds to a traffic flow from the intersection v_x to intersection v_y and the number of vehicular users is known. Each traffic flow $t_{x,y} \in T$ denotes a known set of traffic, $|t_{x,y}|$ denotes the number of vehicles on the traffic flow $t_{x,y}$. There is a merchant s_1 in the graph, and the detour distance $d_{4,5,1}$ represents the vertical distance from the traffic flow $t_{4,5}$ to the merchant s_1. If we place a RSU in the intersection v_4, and it's traffic flow cover set is $\{t_{1,4}, t_{3,4}, t_{4,5}, t_{4,7}\}$. Noted that although $t_{4,5}$ is not covered by RSU totally, it is also considered to be in the traffic flow cover set according to our assumption.

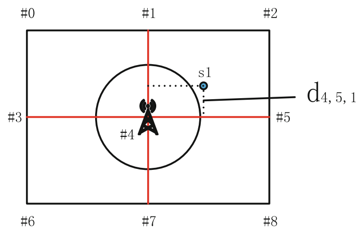


Fig. 2. An example of traffic flow cover set

3.2 Problem Formulation

Our problem can be viewed as : *Given the budget constraint and the distribution of traffic conditions, our goal is to optimize the deployment of the hybrid roadside device for the merchants to maximize their benefit from advertisement dissemination.*

First, we give the definition of merchants' benefit. When a roadside device (like a RAP or RSU) is placed on intersection v_k, we can denote the total benefit obtained by each merchants advertisement as follow:

$$\begin{cases} M_{i,k,p} = \sum_{j=1}^{m} \sum_{t_{x,y} \epsilon T^{k,p}} |t_{x,y}| \times f(att_{i,j}, d_{x,y,i}) \times utl_{i,j} \\ M_{i,k,u} = \sum_{j=1}^{m} \sum_{t_{x,y} \epsilon T^{k,u}} |t_{x,y}| \times f(att_{i,j}, d_{x,y,i}) \times utl_{i,j} \end{cases} \tag{3}$$

If the distance from the merchant to the traffic flow which covered by roadside device does not exceed the predetermined threshold D, this merchant is considered to be served availably. As we consider these merchants are dispersed in the periphery of the main traffic artery, and the roadside device like RAP or RSU is deployed on intersections of these traffic flows. x_i and y_i are used to represent whether this intersection is deployed by a RSU or a RAP:

$$x_k = \begin{cases} 1, & \text{if there is a RAP placed on the intersection}\, v_k \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

$$y_k = \begin{cases} 1, & \text{if there is a RSU placed on the intersection}\, v_k \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

According to the above assumption, merchants obtain their benefits mainly by advertisements. So we define the merchants total benefit E as follow:

$$E = \sum_{k=1}^{q} (M_{i,k,p} \cdot x_k + M_{i,k,u} \cdot y_k) \tag{6}$$

Therefore, our problem can be formulated as follows:

$$\max E = \sum_{k=1}^{q} (M_{i,k,p} \cdot x_k + M_{i,k,u} \cdot y_k) \tag{7}$$

subject to:

$$C_p \cdot n_p + C_u \cdot n_u \leq B \tag{8}$$

$$(dev_i.x - dev_j.x)^2 + (dev_i.y - dev_j.y)^2 \geq R^2_{min\{dev_i, dev_j\}} \tag{9}$$

$$x_i + y_i \leq 1 \tag{10}$$

$$x_i, y_i \in [0, 1] \tag{11}$$

Constraint (8) denotes that the total deployment cost should be less than the given budget B, where C_p and C_u represents the placement cost of RAPs and RSUs respectively and n_p and n_u represents the placement number of RAPs and RSUs respectively. Constraint (9) denotes the distance $(dev_i.x - dev_j.x)^2 + (dev_i.y - dev_j.y)^2$ between the *i-th* roadside device and the *j-th* roadside device should not be less than the minimum of their transmission range. Constraint(10) ensures only one device can be deployed on each intersection. Constraint (11) guarantees that x_i and y_i only choose 0 or 1.

4 Our Solution

In this section, we give our greedy algorithm, which choose an intersection with high merchants benefit and low placement cost greedily to place a roadside device. Therefore, we define a benefit cost ratio when we install a roadside device in the intersection. As the total benefit E is shown as the Eq.(7). We define the total deployment cost C as follow:

$$C = n_p * C_p + n_u * C_u \tag{12}$$

Therefore, we define the benefit cost ratio Δ as follow:

$$\Delta = \frac{E}{C} \tag{13}$$

The benefit cost ratio is the ratio of merchants benefit and placement cost for roadside device. The higher ratio indicates that the current point has more opportunities to be selected to deploy a roadside device. On the contrary, the lower ratio indicates that it has less benefit and huge cost.

Base on the definition of benefit cost ratio, the main idea of our proposed algorithm are as follows: According to the current commercial distribution and traffic situation, the algorithm calculates the current benefit cost ratio iteratively. Then, it selects an intersection with the maximum benefit cost ratio to place the roadside device. Repeating the above two step until all merchants are covered. Our hybrid greedy algorithm is presented as Algorithm 1.

Algorithm 1. Hybrid Greedy algorithm

Input :
The set of merchants: $\{S\}$;
The set of traffic flows: $\{T\}$;
The set of intersections: $\{V\}$;
The budget for deployment: B;
Output :
$\mathcal{R}$: The placement set of RAPs and RSUs
Marking all merchants to be uncovered and Initializing:
x_i=0,y_i=0,n_p=0,n_u=0;
while All the merchants has not been covered **and** current cost less than B **do**
  Computing the benefit cost ratio Δ of all the intersection;
  Selecting a intersection v_k which has the maximum benefit cost ratio;
  Deploying the related device:$\mathcal{R} = \mathcal{R} \bigcup v_k$;
  Marking the related intersection:x_k=1,$n_p = n_p$+1 OR y_k=1,n_u=n_u+1;
  Marking the covered merchants;
end while;
return $\mathcal{R}$;

Figure 3 shows an illustrative example of the greedy algorithm and our placement solution. The graph contains 18 intersections, which labeled from #0 to #17. The graph also has 27 traffic flows, such as $t_{0,1}$, $t_{1,2}$, ..., etc. The set of traffic flows covered by RSU is $\{t_{12,13}, t_{13,14}, t_{10,13}, t_{13,16}\}$, and RAP's is $\{t_{3,4}, t_{4,5}, t_{6,7}, t_{7,8}, t_{9,10}, t_{10,11}, t_{1,4}, t_{4,7}, t_{7,10}, t_{10,13}\}$. The traffic flow coverage set refer to the Eq. 2. So RAP's traffic flow coverage set at intersection v_7 is $\{s_1, s_2, s_3, s_5, s_6\}$, and RSU's traffic flow coverage set at intersection v_{13} is $\{s_3, s_4, s_6\}$. The graph have 6 merchants, which should be covered by our algorithm. In the first iteration, we calculate benefit cost ratio of is 0.834 when place a RSU at v_{13}, which has the maximum benefit cost ratio. The merchants s_3, s_4 and s_6 are covered. In the second iteration, we calculate benefit cost ratio of

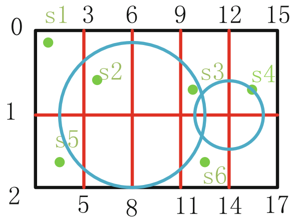


Fig. 3. A example of our solution

is 0.813 when place a RAP at v_7, which has the maximum benefit cost ratio. Then, all the merchants has been covered and the algorithm is ended. So our placement solution is place a RAP at v_7 and place a RSU at v_{13}.

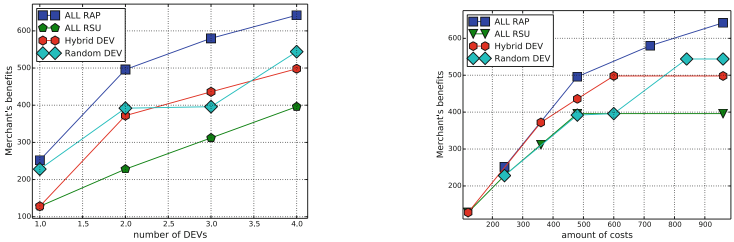
5 Performance Evaluation

In our simulation, four algorithms are used for comparison. (1) All RAPs placement (All RAP), we only deploy RAPs in the simulation. (2) All RSUs placement (All RSU), we only deploy RSUs in the simulation. (3) Hybrid roadside devices placement (Hybrid DEV), our hybrid greedy algorithm, which could choose both RAP and RSU to be placed. (4) Random roadside devices placement (Random DEV), which select the intersection and roadside device randomly.

The parameter setting were given as follows: The grid size is $24 * 20$, there is a total of ten merchants dispersed in specified region. Every traffic flow from one intersection to another intersection has different number of passing vehicular users, and here we employed a series of random number (ranges from 40 to 120) to simulate the traffic flow. The radius of RAPs' coverage is set to 6, and 3 for RSUs. And the threshold D for detour distance is set to 10. while advertisements attraction ratio of all merchants are set to 0.5, the potential benefit for each advertisement is set to 1. The budget for placement is set to 1000. Every RSUs' cost for deployment is 120 while RAPs' cost is 300. Finally, we compared four kind of algorithms through the analysis of impacts between the number of placement devices and following parameters: the overall benefits of merchants, the number of merchants, and the coefficient ratio.

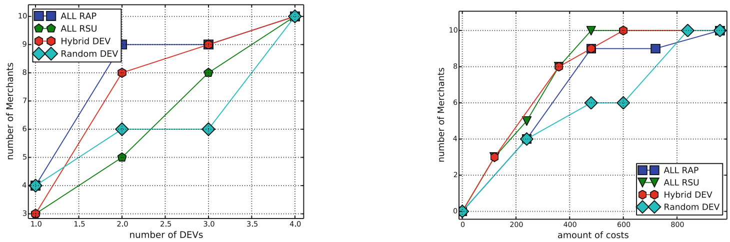
Figures 4, 5 and 6 shows the impacts of the merchants' benefits, number of merchants and benefit cost ratio. As shown in Fig. 4, the number of placed devices increases, merchants benefits grows increases too. Due to different roadside device has different transmission coverage, they may contribute to varying degrees of increase on merchants benefits. Especially when some merchants are covered repeatedly, even no extra benefits can be obtained by the placement of these devices.

In Fig. 5, our algorithm has the lowest placement cost than other algorithms. Based on these deployed devices, more and more traffic flows and related merchants are covered. The number of merchant increases up until all merchants in a specified region are covered or no more expenses anymore.



(a) Number of Devices Vs. Benefits (b) Cost Vs. Benefits

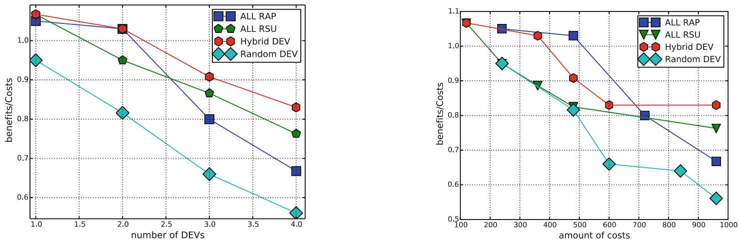
Fig. 4. Impact of the benefits



(a) Number of Devices Vs. Merchants (b) Cost Vs. Merchants

Fig. 5. Impact of merchants

In Fig. 6, it also proves that our algorithm placed the device at the best intersection to have a better gain of each step. With more and more devices are placed, there are fewer merchants who have been not covered by any roadside device. As shown in Fig. 6a and b, the benefit cost ratio declines with the number of placement roadside device. This is because each selection of our algorithm is most valuable.



(a) Number of Devices Vs. Ratio (b) Cost Vs. Ratio

Fig. 6. Impact of the coefficient ratio

6 Conclusions

In this paper, we study hybrid roadside devices placement problem for advertisement dissemination in VCPS. Then, we propose a greedy algorithm which could attract more customers and maximize the merchants benefits. Extensive simulations show that the performance of our proposed algorithm is superior to the other algorithms.

References

1. Li, X., Qiao, C., Hou, Y., Zhao, Y.: On-road ads delivery scheduling and bandwidth allocation in vehicular CPS. In: 2013 Proceedings IEEE, INFOCOM, pp. 2571–2579. IEEE (2013)
2. Zheng, H., Wu, J.: Optimizing roadside advertisement dissemination in vehicular cyber-physical systems. In: 2015 IEEE 35th International Conference on Distributed Computing Systems (ICDCS), pp. 41–50. IEEE (2015)
3. Yan, T., Zhang, W., Wang, G., Zhang, Y.: Access points planning in urban area for data dissemination to drivers. IEEE Trans. Veh. Technol. **63**(1), 390–402 (2014)
4. Li, P., Huang, C., Liu, Q.: Delay bounded roadside unit placement in vehicular ad hoc networks. Int. J. Distrib. Sens. Netw. **2015**, 77 (2015)
5. Reis, A.B., Sargento, S., Neves, F., Tonguz, O.: Deploying roadside units in sparse vehicular networks: what really works and what does not. IEEE Trans. Veh. Technol. **63**(6), 2794–2806 (2014)
6. Ke, W.C., Liu, B.H., Tsai, M.J.: The critical-square-grid coverage problem in wireless sensor networks is NP-complete. Comput. Netw. **55**(9), 2209–2220 (2011)
7. Silva, C.M., Aquino, A.L., Meira, W.: Deployment of roadside units based on partial mobility information. Comput. Commun. **60**, 28–39 (2015)
8. Zhang, B., Jia, X., Yang, K., Xie, R.: Design of analytical model and algorithm for optimal roadside AP placement in VANETs. IEEE Trans. Veh. Technol. **PP**(99), 1–11 (2015)
9. Li, P., Liu, Q., Huang, C., Wang, J., Jia, X.: Delay-bounded minimal cost placement of roadside units in vehicular ad hoc networks. In: IEEE International Conference on Communications (ICC), pp. 6589–6594. IEEE (2015)
10. Lin, C.C., Deng, D.J.: Optimal two-lane placement for hybrid VANET-sensor networks. IEEE Trans. Industrial Electronics, **62**(12), 7883–7891 (2015)