

A Density-Based RSU Deployment and Optimization Heuristic Method for Vehicular Networks

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Abstract— The promising vision and high demands of autonomous driving accelerate the development of vehicular communications. To guarantee the safe operation of vehicles, the wireless access communication network with seamless radio coverage capability is the cornerstone. In this paper, we investigate the network deployment and optimization for vehicular communication networks and propose a density-based heuristic method. We assume that the roadside units (RSU) are deployed on the static public street lamps for equipment cost savings. An optimization problem is formulated to minimize the equipment costs while satisfying the seamless radio coverage condition. To solve the problem, we use a heuristic method and propose a novel density-based algorithm to cope with it. Specifically, we assume an RSU is deployed on a street lamp and make a statistic of the nearby street lamps located within its radio coverage range, which is regarded as the density metric. The higher density is, the higher priority it is chosen. Then, we repeat the above steps until all lamps are covered by RSUs. The simulation results show that our proposal can not only guarantee the seamless radio coverage requirement but also reduce the equipment expenditure significantly, enhancing the safety and reliability of vehicle-to-everything (V2X) wireless communication greatly.

Keywords— Vehicular Communications, Network Design, Network Optimization, Heuristic Method, Density-Based Solution

I. INTRODUCTION

As an important part of modern intelligent transportation system, the vehicle ad hoc network (VANET) improves the road safety and traffic operation efficiency through wireless communication technology greatly [1]. Besides, it provides multiple Internet entertainment service while assisting safe driving to improve the traffic experience of drivers and passengers. As an auxiliary communication facility of VANET, roadside units (RSUs) can cope with the dynamic topology changes caused by the movement of nodes in VANET, which can improve the communication quality between vehicle nodes efficiently [2]. However, the large-scale deployment of RSUs will not only bring high installation and maintenance costs, but also faces the following difficulties: (1) The selection of the optimal RSU deployment point from

the large set of candidate deployment points for RSUs is complex. (2) The deployment of RSUs is influenced by many factors, such as traffic characteristics, the number of RSUs that can be deployed, and the topology and geographic characteristics of the road network. Consequently, how to choose the optimal location to deploy RSUs and achieve regional coverage to enhance network connectivity has become an important issue under the condition of limited number of RSUs.

Currently, some campaigns have been conducted to investigate this issue. The performance of RSU deployment scenarios in VANET is usually measured by 3 factors, i.e., the radio area coverage, the cost of installing and maintaining facilities, and the latency of RSU-assisted information transmission [3]. In [4], Barrachina *et al.* proposed a density-based RSU deployment method, which tries to achieve an efficient system with the lowest equipment cost. They defined the density, which uses an inverse proportion to the expected density of vehicles, and the corresponding simulations reveal that it can reduce the RSU number evidently. In [5], the authors established an RSU deployment problem and focused on balancing the efficiency and coverage based on traffic demands. They aimed to optimize both the average data transmission delay as well as and the number of vehicles covered by RSUs. In [6], Gao *et al.* investigated the one-dimensional RSU deployment problem and proposed two greedy algorithms. In [7], Xue *et al.* introduced a connectivity-oriented RSU deployment scheme, which aims to maximize vehicle-to-infrastructure (V2I) communication performance. Simulation results prove that it can cover most vehicles with a reduced RSU number.

These efforts provide insights into the RSU deployment. However, few of them consider the RSU deployment by utilizing the existing street lamp layout. Consequently, we aim to explore this issue herein. The remaining of this paper is organized as follows. In Section II, we introduce the RSU deployment situation and formulate a deployment optimization problem aiming to realize seamless radio coverage requirement and to minimize the equipment expenditure. In Section III, we propose a novel density heuristic algorithm to solve this issue. Section IV presents the

corresponding simulation works and the final conclusions are drawn in Section V.

II. SYSTEM MODEL

As shown in Figure 1, we assume that all RSUs are deployed on the existing street lights for a specific scenario, of which the corresponding positions are known in advance. The merits of this assumption lie in the fact that it can make full use of street light equipment including power supply, wire communication, etc. For all RSUs, the maximal transmit power is the same, but the radio coverage area is subjected to the propagation environment. As shown in Figure 1, two RSUs cover a circular area with different radii. Under the same transmit power, the corresponding coverage radius is larger in the open area than that in a narrow area. Let $\mathbf{R}=[r_q]_{Q \times 1}$ denote the RSU coverage matrix, where Q means the total number of RSU. The lamp set and RSU set are marked as $\mathcal{V}_L$ and $\mathcal{V}_R$, respectively. Consequently, our goal is to determine the RSU number and which street light to hang to realize seamless radio coverage for vehicular communications.

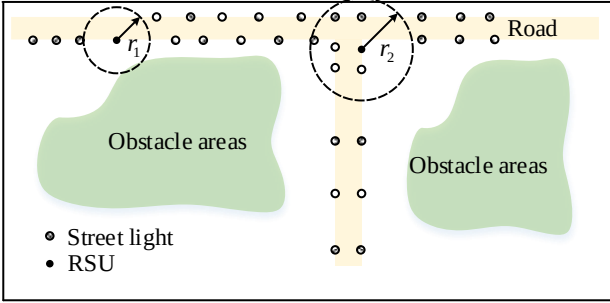


Figure 1. A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

Let P denote the total number of street lamp, then this goal can be expressed as

$$\min \left\{ \sum_{p,q} \lambda \alpha_{pq} \right\} \quad (1)$$

where λ is the equipment cost per RSU, $\alpha_{pq} \in \{0,1\}$ indicates the binary variable whether the p -th RSU is placed on the q -th street lamp. Besides, it is constraint by

$$\sum_q \alpha_{pq} = 1, \quad (2)$$

$$\sum_{p,q} \alpha_{pq} = Q, \quad (3)$$

where constraint (2) means that an RSU can only be placed on a street lamp. Constraint (3) infers that the total number of RSU is Q . The total number of street lamp is denoted as P . Then, we construct a distance matrix for all street lamps, which is expressed as

$$\mathbf{D} = \begin{pmatrix} 0 & d_{12} & \cdots & d_{1P} \\ d_{21} & 0 & \cdots & d_{2P} \\ \vdots & \vdots & 0 & \vdots \\ d_{P1} & d_{P2} & \cdots & 0 \end{pmatrix} \quad (4)$$

For an element located in the i -th row and the j -th column of $\mathbf{D}$, it means the distance between the i -th and the j -th street lamps. Obviously, the elements of the matrix diagonal are 0 as a result of zero separations.

When deploying the RSUs on street lamps, we aim to reduce the RSU equipment cost under the condition of seamless radio coverage for all lamps. In other words, every lamp should be covered by at least one RSU. Take the street lamp l_m as an example, it is covered by at least one RSU, i.e.,

$$\mathbf{D}(\alpha_{p,q} p, m) \leq r_p, \forall m \in \{1, 2, \dots, P\} \quad (5)$$

with a constraint of

$$\alpha_{p,q} = 1, \exists p \in \{1, 2, \dots, P\}, \exists q \in \{1, 2, \dots, Q\} \quad (6)$$

Besides, the number of RSU should be less than the number of street light, which is

$$Q \leq P \quad (7)$$

or

$$Q = \sum_p \sum_q \alpha_{p,q} \quad (8)$$

Finally, our goal is formulated in EQ.(1) with several constraints of EQ.(5-8).

III. PROBLEM SOLUTION

In this section, we will provide a detailed solution to the formulated problem. Since it is an NP-hard problem, it is impossible to find the optimal solution within a given finite time or steps. Hence, we propose a density-based heuristic algorithm to solve this problem herein. Our method contains 3 phases and is elaborated as follows.

(1) Calculate the density of each road lamp. For a given lamp l_q , we first assume that an RSU is placed on it and find those nearby lamps located within its radio coverage range. Specifically, if a lamp satisfies the following condition, i.e.,

$$\|\mathbf{p}(m) - \mathbf{p}(q)\| \leq R(q) \quad (9)$$

which means that it is located within the radio coverage of l_q .

Let V_q represent those lamps satisfying the above condition of l_q . Then its corresponding density, denoted as $s(q)$, is measured by the number of street lamps located within its radio coverage range, i.e., $s(q) = |V_q|$. Calculate the density for all lamps and obtain the density list $\mathbf{s}$.

(2) Sort the density list $\mathbf{s}$ in descending order, i.e., $\mathbf{s}'$. Take out the 1st lamp in $\mathbf{s}'$, marked as $l_{p'}$, and find those lamps located within its range, denoted as $V_{q'}$. This lamp is designated to place an RSU. Then, delete the 1st lamp together with the corresponding $V_{q'}$ in $\mathbf{s}'$, i.e.,

$$\mathbf{s}' = \mathbf{s}' - (l_{p'} \cup V_{q'}) \quad (5)$$

Afterwards, delete an RSU in $\mathcal{V}_R$.

(3) Repeat step (2) until it satisfies the iteration termination conditions, i.e., the density list is empty $\mathbf{s}' = \emptyset$ or the rest available RSU set is empty $\mathcal{V}_R = \emptyset$.

Based on the above algorithm, we can determine the RSU deployment positions under the condition of seamless radio coverage.

IV. SIMULATION ANALYSIS

In this section, we will conduct some simulation works and verify our proposal. The simulation scenario with a size of about $300\text{m} \times 250\text{m}$ is presented in Figure 2 and Figure 3, where yellow circles mean the radio coverage for given street lamps. The blue scatterers represent the street lamps, which can be identified as two clusters. The first bunch of scatterers is assumed to be located in an empty rural environment with fewer obstacles and the corresponding RSU coverage radius R_{rural} is set to 30 meters per RSU. Whereas the second cluster is located in an urban scenario with mass obstacles. The corresponding RSU coverage radius R_{urban} is set to 20 meters per RSU. Obviously, the corresponding RSU coverage at the first cluster is larger than that in the second cluster.

TABLE 1. SIMULATION PARAMETER VALUES

Parameter	Value	Parameter	Value
Lamp number	100/200/300	Lamp cluster number	2
R_{rural}	30 m	R_{urban}	20 m

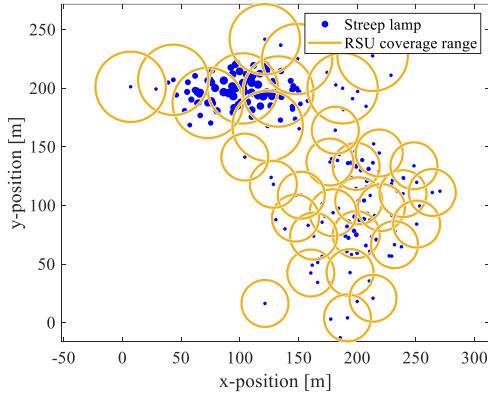


Figure 2. The Diagram of RSU deployment based on our proposed density-based heuristic strategy

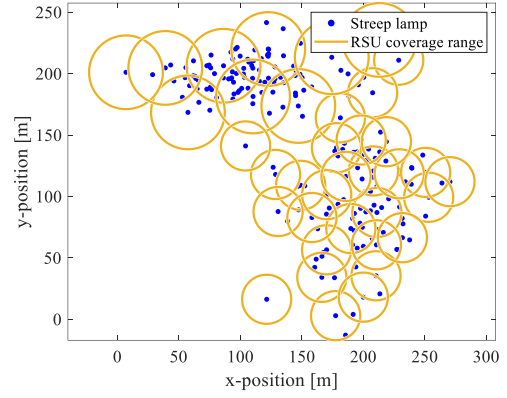


Figure 3. The Diagram of RSU deployment based on the random strategy

To better highlight the benefits of our proposed heuristic strategy, we also compare the results with the random strategy with different street lamp numbers as shown in Figure 4. Specifically, we randomly generate street lamps with different numbers within the same simulation area. The corresponding RSU number results are plotted in Figure 4.

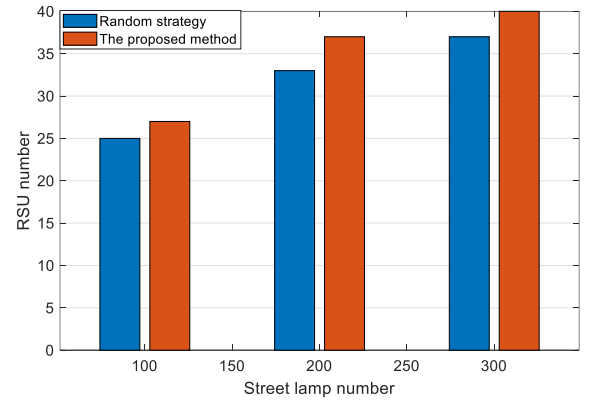


Figure 4. The Diagram of RSU deployment based on our proposed density-based heuristic strategy

From the above figure, we can learn that our proposal requires less number of RSUs compared to the random strategy, proving a better method.

V. CONCLUSIONS

In this paper, we focus on the RSU deployment for vehicular communication networks based on existing street lamps. We formulate an optimization problem aiming to minimize the RSU equipment cost while providing seamless radio coverage for all street lamps. Since it is an NP-hard issue, we propose a novel density-based heuristic method to cope with it. The relevant simulation results show that our proposal can yield lower RSU equipment costs compared with the random strategy while guaranteeing seamless radio coverage for all street lamps. Our findings provide some insights into the V2X wireless communications.

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