A Multi-objective Roadside Units Deployment Method in VANET

1st Zihui Zhang
Institute of Automation
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China
zihuizhang@foxmail.com

2nd Chao Li
Institute of Automation
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China
lichao_silent@foxmail.com

3rd Liangjie Yu
Institute of Automation
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China
embedos@126.com

4th Yiqiang Zhao
Institute of Automation
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China
zhaoyiqiang@sdas.org

5th Yanqiang Li
Institute of Automation
Qilu University of Technology
(Shandong Academy of Sciences)
Jinan, China
liyq@sdas.org

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***Abstract*—In the past ten years, the Vehicular Ad Hoc Networks (VANET) has been widely incorporated into intelligent transportation systems (ITS) and advanced assisted driving (ADAS), effectively promoting traffic management and autonomous driving Application development. Reasonable deployment of Roadside Units (RSUs) can greatly improve the performance and efficiency of VANET, which becomes a key issue. This paper proposes a multi-objective RSUs optimization model, which also considers the three optimization objectives of RSUs deployment cost, communication delay and coverage area, and uses the NSGA-II algorithm to solve the Pareto optimal solution set of the problem. Finally, the method in this paper is verified by a numerical simulation of the urban street RSUs deployment problem.**

***Keywords*—Roadside Units Deployment, VANET, Multi-objective optimization, NSGA-II**

I. Introduction

As one of the important application technologies of V2X, VANET refers to a wireless ad hoc network of mobile vehicles supported by optional infrastructure, mainly through V2V communication between vehicles and V2I communication between vehicles and roadside facilities. Generally speaking, VANET mainly includes two kinds of nodes (nodes), On-Board Units (OBUs) and Roadside Units (RSUs). Among them, OBUs are installed on vehicles, and RSUs are usually installed on both sides of the road or at intersections[1]. VANET has some typical shortcomings of ad hoc network, such as rapid topology changes, unstable connection speed, poor reliability, etc., especially when communicating through V2V alone, it often fails to meet the delay boundary requirements. As an auxiliary communication facility in VANET, RSUs can effectively solve the dynamic change of the network topology caused by the rapid movement of vehicles, effectively efficiently eliminate the problem of VANET access through V2I, thereby improving the quality of communication between vehicle nodes[2].

Due to the limitation of the communication range of RSUs, it is almost impossible to achieve full coverage of VANET in a larger area by deploying RSUs in actual scenarios. Therefore, RSUs Deployment (RSUD) has become representative research so far. That is, when the number of RSUs is limited, how to choose the best location to deploy RSUs to achieve the largest possible area coverage and improve the communication performance of the network has become a key part [3]. At present, studies have pointed out that the utilization rate of RSU equipment is the highest when it is arranged at the intersection of roads[4]. When the number of RSUs is small, the coverage area of V2X communication will be reduced, so that more V2V communication is used to replace the faster V2I communication, which may cause communication delay.. However, an increase in the number of RSU equipment will greatly increase the cost and cause a waste of resources when there are fewer vehicles. RSUD needs to meet multiple optimization goals, and each goal influences and contradicts each other, which is a multi-objective optimization problem.

The main purpose of this paper is to propose a RSUD multi-objective optimization model, and use the multi-objective evolutionary algorithm NSGA-II to solve the Pareto optimal solution set of the problem. This article is organized as follows. In Section 2, we review some previous studies about RSUs deployment. A multi-objective roadside units deployment method is proposed in Section 3.Take the RSUs deployment problem of urban streets at an 8*8 intersection as an example, the results are analyzed and discussed in Section 4. Finally, our work and prospects are concluded in Section 5.

II. Related Work

In recent years, many researchers have devoted themselves to solving the problem of RSUs deployment and have made great progress. RSUD can be classified into two categories: fixed RSUD and mobile RSUD. most RSUs are considered to be fixed to work in a specific location[5]. There are also some studies that consider the deployment of mobile RSUs. Kim et al. proposed to deploy RSUs on a special vehicle so that it can travel along a predetermined route and realize that RSUs can cover multiple areas at the same time [6]. In practical applications, fixed RSU is more commonly used than mobile RSUs deployment, so this article focuses on the deployment of fixed RSUs.

For the RSUs deployment problem, researchers use various optimization methods to solve it. Mehar et al. modeled the RSUs layout problem as an optimization problem, and uses the genetic algorithm and Dijkstra algorithm to reduce the number of RSUs based on the deliverance time requirement and the deployment cost[7]. Li et al. deployed two RSUs with different communication ranges and costs at the same time, and used a two-stage algorithm to find the best location of the two RSUs to minimize the total cost and meet the delay boundary in a given area [8]. Yang et al. proposed a binary differential evolution algorithm to maximize the number of roads covered by the deployment of RSUs, and set the communication delay boundary as a constraint condition[3].

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Manuelet et al. proposed a genetic algorithm for roadside unit deployment (GARSUD) system, which is capable of automatically providing an RSUs deployment suitable for any given road map layout[9]. Shi et al. proposed a RSUD message propagation model based on the V2X network, and used a neighborhood search algorithm based on central rules (CNSA for short) to select the RSU installation location under a given budget[10]. These works use different optimization methods for a variety of scenarios, especially the choice of optimization targets has a greater impact on the RSUs deployment plan.

The optimization goals of RSUs deployment problems mainly include three categories: RSUs deployment cost, RSU coverage and data transmission delay, some other optimization goals are derived on this basis. The deployment cost of RSUs is directly proportional to the number of RSUs, which is the goal adopted by most studies[11]. RSUs coverage mainly refers to the coverage of a given area, and reduces the overlap of the coverage area between RSUs, so that it can be treated as a type of combined optimization problem[12]. It is also possible to convert the RSUs coverage of the area into the coverage of the roads in the area, thereby effectively reducing the search space of the solution[5]. The communication performance of RSUs deployment is usually expressed by delay-bounded, that is, the communication delay of each RSUs cannot exceed a given bounded delay for data transmission[8]. Although some researchers have used multi-objective evolutionary algorithms to solve the RSUs deployment problem[13], most of them solve the above one or two optimization goals, or treat the optimization goals as constraints. This approach lacks a comprehensive solution and analysis of the various optimization objectives of the RSUs deployment problem.

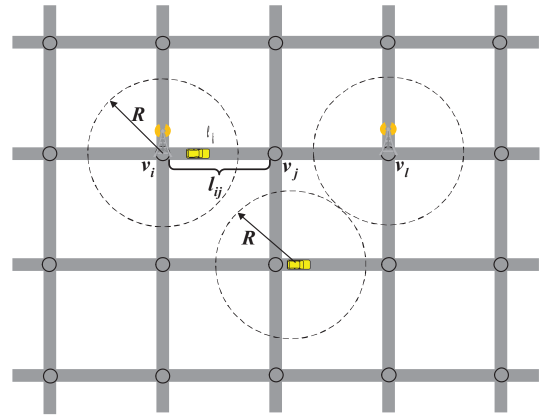
III. Model and Algorithm

A. Multi-objective model of RSUD

In the method of this paper, the urban road is modeled by a weighted graph $G=(V,E)$ [10], $V=\{v_1,v_2,...v_N\}$ represents a collection of vertices, N is the number of intersections. $E=\{e_1,e_2,...,e_M\}$ represents the collection of all road segments, M is the number of edges between two adjacent vertices. If the two vertices of an edge are v_i and v_j, then this edge can also be expressed as $e_k=\{l_{ij},\rho_{ij},v_{ij}\}$. Where l_{ij}, ρ_{ij}, and v_{ij} are the Euclidean distance, vehicle density, and average speed of the segment respectively. R is the communication radius between a vehicle and RSU, as shown in Figure 1.

This paper gives a multi-objective optimization model, which comprehensively considers the number of RSUs, RSUs coverage area and data transmission delay.

$$F(x)=\{f_1(x),f_2(x),f_3(x)\}$$
$$s.t.\quad x_i=\begin{cases}1, \text{ RSU deployed}\\ 0, \text{ No RSU deployed}\end{cases} \tag{1}$$



○ **Candidate intersection for RSUs Deployment**

Figure 1. Schematic diagram of urban street RSUs deployment

Where $f_1(x)$ is the RSUs deployment cost, which is mainly determined by the number of RSUs, $f_2(x)$ is the coverage area of RSUs, $f_3(x)$ is the sum of expected communication delays in the area where RSUs need to be deployed. $x=\{x_1,x_2,\ldots,x_N\}$ is the scheme of RSUs deployment, N is the number of intersections. When the RSU is deployed at the i-th intersection, the value of x_i is 1, otherwise the value is 0.

(1) Number of RSUs

This article studies the deployment of a variable number of RSUs, that is, explores how to deploy the least number of RSUs to achieve the largest VANET communication coverage area and minimize the expected delay of the roads in the area. Optimization objective of RSUs quantity is shown in formula (2).

$$f_1=\min\sum_{i=1}^{N}x_i \tag{2}$$

(2) Coverage area

Because the number of roads in the urban environment of this article is relatively dense, and RSUs are deployed at intersections, and each RSU can cover multiple streets, this article uses the coverage area of RSUs as the optimization goal. To simplify the calculation, the coverage area is taken as a negative value. The smaller the overlapping coverage area between deployed RSUs, the better the effect. The optimization objective of coverage area is shown in formula (3).

$$f_2=\min\sum_{i=1}^{N}-(\pi R^2-\sum_{j=i+1}^{N}\Delta A_{ij})\cdot x_i \tag{3}$$

Where ΔA_{ij} is the overlapping area of any two RSUs transmission range, also known as the interference area.

(3) Communication delay

Research in the past generally used delay boundary of data transmission as a constraint[3]. In this paper, we directly takes the overall communication delay as the optimization objective in the RSUs deployment area, which is shown in formulas (4)-(6).

$$f_3 = \min \sum_{k=1}^{M} T_k \tag{4}$$

$$T_k = \begin{cases} t_{hop} = \dfrac{p_{size}}{s}, & 0 \le d_{ij} \le R \\ \min\{disk[i], disk[j]\} + t(i,j), & d_{ij} > R \end{cases} \tag{5}$$

$$t(i,j) = (1 - e^{-R \cdot \rho_{ij}}) \cdot \frac{l_{ij} \cdot t_{hop}}{R} + e^{-R \cdot \rho_{ij}} \cdot \frac{l_{ij}}{v_{ij}} \tag{6}$$

Where T_k is the expected delay of the road section e_k, and d_{ij} is the distance between the points v_i and v_j at both ends of the road section e_k to the nearest RSU device. If the road section is within the coverage of RSU, the expected delay is the time of single-hop transmission t_{hop}, p_{size} is packet size, s is data rate. If the road section is not within the coverage of the RSU, multi-hop transmission needs to be calculated. $disk[i]$, $disk[j]$ is the minimum transmission time from both ends of e_k to the RSU, and $t(i,j)$ is the expected packet-forwarding delay from v_i to v_j through the recursive function call the T_{k-1} or T_{k+1} for calculation.

B. NSGA-II algorithm

To verify above model, we need to use a multi-objective evolutionary algorithm to obtain the Pareto optimal solutions. The current research on multi-objective optimization algorithms has made great progress, and researchers have proposed many excellent algorithms[14]. Because this article focuses on the improvement of the problem model rather than the algorithm, the most widely used NSGA-II[14] is chosen to solve RSUD problem, which has the advantages of simple structure and fast calculation speed.

In NSGA-II, each generation of population generates new individuals through crossover and mutation, and merges with the original parent individuals in the population to form a new population. In order to maintain the fixed size of the population, non-dominated sorting and crowding distance calculation are performed on the merged population. According to the ranking results, the outstanding individuals are retained to generate a new generation of populations.

The main feature of NSGA-II is to perform non-dominated sorting and crowding distance calculation. Non-dominated sorting classifies the non-dominated individuals in each sorting to the same level, and assigns the same fitness value. Among them, the first-level non-dominated front faces generally have the best fitness value, making them have a greater chance of being selected or copied than other individuals in the population. In the selection operation, first non-dominated levels of the two individuals will compare the crowding distance. The individual with the larger crowding distance will be selected first.

IV. RSUD CASE VERIFICATION

A. Configuration

To verify the model, this article takes an ideal urban roads as an example, which has 8*8 vertical and horizontal intersection with uniform distribution. The area size is 3.6 km*3.6km, and RSUs can only be installed at the intersection, as shown in Figure 1. The length of each road segment is 400 meters, the density of vehicles on the road segment is randomly generated according to a uniform distribution of 10-120 vehicles/km. Assuming that under moderate traffic density, the average speed of vehicles on the road segment is obtained based on the straight-line relationship[16]. The communication range of RSU is 280 meters. p_{size} =1KB, s =3Mb/s.

The NSGA-II algorithm uses a 0-1 encoding method. Each individual algorithm contains 64 genes, and each gene represents whether an RSU is deployed at an intersection. Through many experiments, we set the crossover rate is 0.9, the mutation rate is 0.1, the population size is 200, and the generation is 500.

B. Results and Discussions

The Pareto optimal solution set of the RSUD is obtained through the NSGA-II algorithm. As shown in Figure 2, the abscissa is the number of RSUs, and the ordinate is the coverage area. The bar graph on the right represents the total expected delay. The deeper it is, the darker the color, which means the smaller the value. It can be seen from the figure that the distribution of Pareto's front face is relatively uniform, and the single optimal solution of coverage area and expected delay is on the right end of Pareto's front face, and the optimal solution of the number of RSUs is at the left end of Pareto's front face. This shows that when one of RSUD's objectives is optimal, at least another objective has a poor value. The three optimization objectives restrict each other, and it is impossible to obtain a unique solution for the three objectives at the same time. This is also in line with the theory of multi-objective optimization.

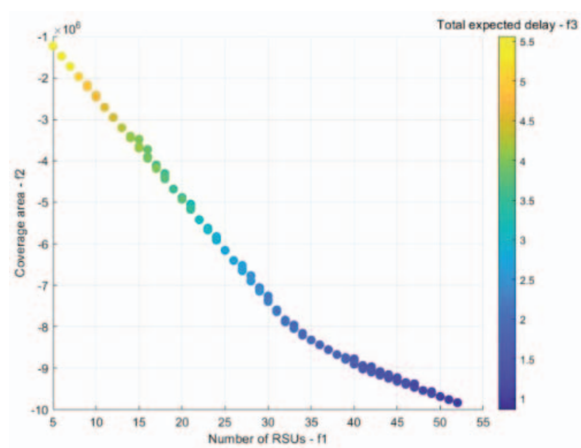
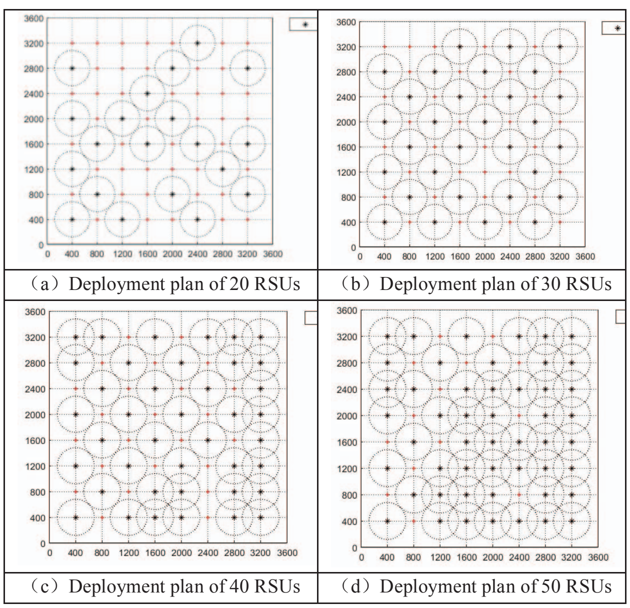


Figure 2. Pareto solution set distribution diagram

TABLE I. OBJECTIVE FUNCTION VALUES IN THE PARETO FRON

Objective function	20 RSUs	30 RSUs	40 RSUs	50 RSUs	mean	std
Number of RSUs f_1	20	30	40	50	28.925	13.203
Coverage area f_2	4926017.280	7389025.921	8772868.333	9681877.603	6533948.565	2576934.231
Total expected delay f_3	484.769	303.864	200.553	140.074	374.795	189.465

To further explore the distribution characteristics of Pareto optimal front, we selected deployment schemes with 20, 30, 40, and 50 RSUs as representatives for analysis, and gave the average and mean square deviation of each target, and each objective function. The values are as seen in Table 1. It can be seen from the table that starting from 30 RSUs, the coverage area has been greatly improved. The expected delay increase of 40 RSUs is also large, and the average value can basically meet the requirements of the delay boundary. Each deployment plan is shown in Figure 3. The coverage area of the deployment plan of 20 RSUs is significantly smaller, and the utilization rate of each RSU in the deployment plan of 30 RSUs is higher, but there are continuous RSUs missing in some locations. Starting from the deployment plan of 40 RSUs, the cross-coverage phenomenon of RSUs began to increase, indicating that redundant RSUs deployments began to appear. Therefore, it is best for designers to choose from the non-dominant solution set of RSUD based on specific road characteristics (traffic flow density and average vehicle speed, etc.) and cost budget.



（a）Deployment plan of 20 RSUs （b）Deployment plan of 30 RSUs

（c）Deployment plan of 40 RSUs （d）Deployment plan of 50 RSUs

Figure 3. Deployment scenarios for different numbers of RSUs

V. CONCLUSIONS AND FUTURE WORK

According to the characteristics of VANET in the urban environment, this article gives a multi-objective optimization model for RSUs deployment, which comprehensively considers three objective including the number of RSUs, the coverage area and the expected delay of data transmission. Then NSGA-II algorithm is used to obtain the Pareto optimal solution set of the RSUD problem. Finally, the method is verified by a case of a urban road in an ideal environment, and the deployment schemes of different numbers of RSUs are analyzed.

The main purpose of this paper is to explore the construction of multi-objective model of RSUD, so the ideal map is used by simulation experiment. In the next research, we will use the Open Street Map(OSM) of real urban roads for further verification. Especially in actual roads, the deployment location selection of RSU equipment is more complicated, and higher requirements are placed on models and algorithms. In the next step, we will also study vehicle-road-cloud(vehicle-road-cloud) system, in order to support for vehicle-road-cloud coordinated control.

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