

RPA: Road-Side Units Placement Algorithm for Multihop Data Delivery in Vehicular Networks

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Abstract—This paper proposes **Road-Side Units Placement Algorithm (RPA)** to provide vehicles with the multihop Quality-of-service (QoS) data delivery in vehicular networks using infrastructure nodes, such as road-side units (RSUs) and relay nodes. We consider inbound delivery from RSU to vehicle. We define the QoS of data delivery with the mean and standard deviation of end-to-end data delivery delay. In this paper, we propose a Greedy Set-Cover Algorithm for the selection of intersections to place RSUs. We formulate the RSU deployment problem as the optimal selection of a subset of road intersections for RSUs. In simulation, this algorithm outperforms a uniform deployment and satisfies the required QoS of data delivery in many cases.

I. INTRODUCTION

Recently, Vehicular Ad Hoc Networks (VANETs) are one of promising research areas [1]–[5]. Like IEEE 802.11p [6], IEEE works for wireless access in vehicular environments (WAVE) and standardizes dedicated short range communications (DSRC) for vehicular networks. Vehicular networks can help driving safety, and intelligent transportation systems (ITS) infrastructure. [7]

In VANETs, data delivery delay is related to the number of APs. In this paper, we define APs in vehicular networks as Road-Side Units (RSUs). However, more RSUs mean more infrastructure cost for vehicular network. Besides, even if the number of RSU is the same, performance can significantly differ by the placement of RSUs. Therefore, the importance of selecting an appropriate number of RSUs and their positions is recognized. In this paper, we propose an RSU placement algorithm that finds a minimal number of RSUs to satisfy required QoS delivery delay and provides better performance even with the same RSU numbers.

We can think many methods for placing RSUs. The easiest way to place RSUs is uniform interval RSUs placement in road networks. In this case, however, the data delivery may not be effective because it does not consider vehicular traffic density. Thus, we propose another algorithm that considers both road traffic and data delivery Quality of Service (QoS).

The remaining part of this paper is composed as follows: Section II summarizes related work. In Section III, we formulate our infrastructure node placement for the data delivery QoS with the relay-node-based forwarding architecture. Section IV describes our RSU placement algorithm. Section V presents the results of our approach. Section VI suggests research issues to study in the future. Finally, Section VII concludes this paper along with future work.

II. RELATED WORK

Recent studies of VANETs have been done about the data forwarding and data dissemination in vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-vehicle (I2V) [1], [3]–[5], [8]–[10]. Data forwarding in VANETs is different from that in Mobile Ad Hoc Networks (MANETs) [11]. First, vehicle movement is limited physically (i.e. roadway). Second, the speed of vehicle is limited by the speed limit of roadway. Third, communication shortest-path does not always match the physical shortest-path because of heterogeneous traffic conditions. These characteristics provide the opportunity to new approaches for data forwarding in VANET.

In SADV [10], Ding et al. propose the packet forwarding strategy using relay nodes for reliable data delivery. SADV focuses on the outbound packet delivery, from vehicle to a fixed point. Because SADV only focus on outbound packet delivery, solution for inbound packet delivery is needed.

TSF [9] proposes an effective solution for data delivery. TSF selects an optimal rendezvous point for the packet and the destination vehicle, using the vehicle trajectory. TSF is originally inbound data delivery solution that forwards packets from a fixed point to a moving vehicle. Besides, it can perform outbound data delivery by considering fixed point as the stationary vehicle. In this paper, we use TSF for packet forwarding strategy.

α -coverage is proposed in [12] for data delivery QoS coverage in vehicular networks. α -coverage is based on data delivery QoS that is defined as the worst-case interconnection gap with APs for communications in vehicular networks. α -coverage considers vehicle moving time for data delivery between a vehicle and AP. In dense traffic case, however, many other vehicles can be used as packet forwarders or packet carriers to reduce end-to-end (E2E) delay. This packet forwarding scheme is discussed in many VANET studies, such as VADD [3], TBD [8], and TSF [9]. Thus, we use TSF for our packet forwarding scheme.

Relay Node (RN) assisted forwarding is a good way to enhance VANET performance. Data forwarding schemes based on stochastic models (e.g., VADD [3]) have problem in packet transmission from RSU to vehicle. In stochastic model, vehicles forward their packets to neighboring vehicles that are expected to deliver packet faster. Because this process relies on probability, this scheme makes huge delivery delay variation due to the stochastic forwarding without relay nodes at

intersections. Packet transmission is failed when packet arrive destination later than destination vehicle because of the huge delivery delay variation. That is why delivery delay variation needs to be smaller in VANET. We place an RN at each intersection to reduce delivery delay variation. RNs perform packet storing and forwarding in the same way with TSF [9] and SADV [10]. It makes the moving direction and path of the packet fixed through the store-and-forwarding at RNs. Thus, the delivery delay variation is reduced by adding Relay Node.

III. PROBLEM FORMULATION

In this section, we formulate our problem as follows:

- Our goal is to place the minimum number of RSUs to reduce packet delivery delay using given vehicular traffic statistics, while satisfying the required QoS of data delivery (i.e., mean delay and delay deviation).
- We focus on the busy road in downtown rather than the slack road in suburbs, because packet forwarding schemes have advantages in dense traffic.

A. Vehicular Network Architecture

We consider a data forwarding scenario in vehicular network architecture, as shown in Fig. 1.

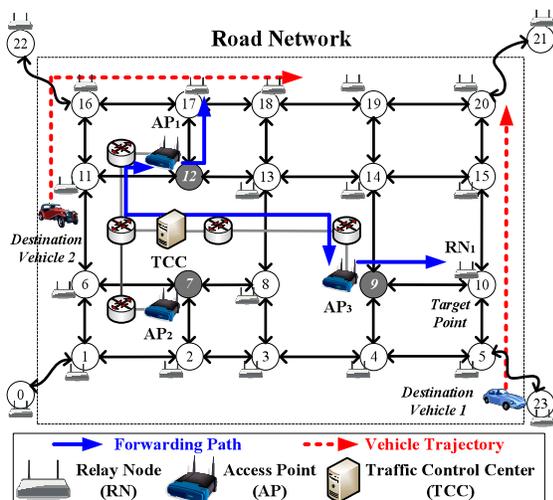


Fig. 1: Scenario of Data Forwarding in Vehicular Network

- **Traffic Control Center (TCC):** TCC is an entity that manages vehicle trajectories [13]. When TCC receives a packet to send, TCC selects the RSU that can transfer packet faster by determining vehicles' current position and movement. After TCC sends a packet to RSU, RSU sends a packet to vehicle.
- **Road-Side Unit (RSU):** RSU is a gateway that connects vehicular networks infrastructure to wireless network. RSU can use DSRC, and all components of vehicular networks infrastructure such as TCC and RSU are connected to each other by wired or wireless networks [5]. RSU receives a packet from TCC and forwarding it to vehicle.
- **Relay Node (RN):** RN is a node that does not connect to any other vehicular networks infrastructures. RN can

use DSRC communication and performs buffering and forwarding packets. We can perform reliable data delivery by deploying RNs. We assume that RN is deployed at each intersection of road networks for the reliable data delivery. However, as the discussion on TSF [9], some intersections may not need to deploy RNs.

- **Vehicles:** Vehicles are participating in VANETs and have DSRC communication interface [6].
- **Quality of Service (QoS):** QoS is defined as the worst-case interconnection gap with APs for data communications in vehicular networks. It is represented as (μ, δ)

B. Assumptions

- Each vehicle, RN, RSU, and TCC has navigation supporting GPS and digital road maps [14], [15]. The navigation can use traffic statistics such as vehicle arrival rate λ and average vehicle speed v per road segment (e.g., Garmin [14] and Waze [16]).
- When driving, drivers enter their destination on navigation. The navigation calculate vehicle trajectory from entered destination position and current position information. Every vehicle participated in vehicular networks transmit their trajectory to TCC via RSU using data forwarding scheme, such as TSF [9] and SADV [10].

IV. RSU PLACEMENT ALGORITHM

In this section, we describe the design of RSU deployment algorithm, *Greedy Set Cover Algorithm*.

When we use a uniform distribution, it is expected that the performance is reasonable. However, the uniform deployment does not consider vehicle traffic. Network coverage is bigger at an intersection with dense traffic than an intersection with light traffic. This means that we can cover a larger area by placing an RSU at an intersection with dense traffic in a target road network for the required QoS delivery delay bound. Thus, a deployment with considering traffic is cost-effective for construct infrastructure of vehicular networks. Thus, we formulate this problem as a set-covering problem.

V: Vertex Set (Intersections)

E: Edge Set (Road Segments)

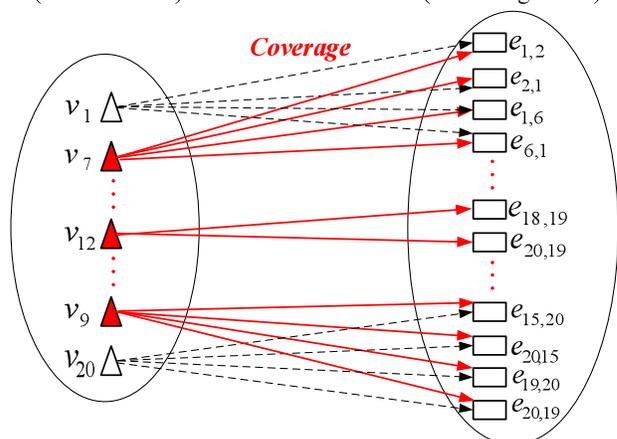


Fig. 2: Set Cover Problem for Vehicular Network Coverage

As shown in Fig. 2, each vertex (i.e., intersection) has its own network coverage, represented as the set of road segments. For example, in Fig. 2, v_7 covers $e_{1,2}$, $e_{2,1}$, $e_{1,6}$, and $e_{6,1}$. This means that intersection 7 can deliver a packet to a vehicle at $e_{1,2}$, $e_{2,1}$, $e_{1,6}$, $e_{6,1}$ in the required QoS delivery delay bound. However, one intersection cannot cover the whole edge set in almost all cases. Thus, we must select multiple RSUs to satisfy QoS. In Fig. 2, for example, we can cover the whole edge set by selecting v_7 , v_{12} , and v_9 . If there is no way to cover the target road network by selecting the three vertices, we can say that we need to select more vertices to satisfy the required QoS delivery delay. However, the set-covering problem is NP-hard problem [17]. Therefore, We design a greedy algorithm that finds a minimal number of subsets rather than the minimum. We use the traditional set-covering algorithm that represented in [17]. Algorithm 1 is the description of Greedy Set-Cover

Algorithm 1 Greedy Set Cover(V, E)

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1:  $Q = \emptyset$ 
2:  $R = V$ 
3:  $U = E$ 
4: while  $U \neq \emptyset$  do
5:   select  $i$  maximizes  $|S_i \cap U|$  for  $i \in R$ 
6:    $U = U - S_i$ 
7:    $R = R - \{i\}$ 
8:    $Q = Q \cup \{i\}$ 
9: end while
10: return  $Q$ 

```

Algorithm. There are two parameters, V and E . V is a vertex set of the intersections in the road map. E is edge set of road segments in the road map. Note S_i is a cover that contains the covered edges (i.e., road segments) by the forward-and-carry of a packet. Thus, this algorithm tries to select a minimal number of intersections for RSUs.

V. PERFORMANCE EVALUATION

In this section, we evaluate the performance of Greedy Set-Cover Algorithm in terms of packet delivery delay, packet delivery cost, and packet delivery ratio.

Our Baselines of the simulation are as follows:

- **Uniform Placement:** It gets a parameter of N that is the number of intersections to select. Next, it divides all vertices into N groups by the order in which they appear on the map. Finally, it selects N vertices that is center of the each group.
- **Random Placement:** It performs similarly to Uniform Placement. The difference is that Random Placement selects a random vertex per group, so selects N vertices for N groups as intersections for RSUs. The reason of the random selection is to let intersections with RSU be naturally dispersed over the road network.

The evaluation setting is as follows:

- **Performance Metric:** We use three values as metric, *packet delivery delay*, *packet delivery cost*, and *packet delivery ratio*.

- **Parameters:** On performance, we investigate the impacts of the following parameters: *Number of Vehicles*, *Vehicle Speed*, and *Vehicle Speed Deviation*.

A. Simulation Configuration

In this section, we describe the simulation configuration of this paper. The simulation configuration is as follows:

- We have built a simulator based on SMPL [23] in C language.
- The grid road network with 49 intersection is used.
- TSF is used for data forwarding, supporting packet-level forwarding without DSRC-based media access control protocol (i.e., IEEE 802.11p).
- City section mobility model [24] and Manhattan mobility model [25] are used for moving pattern of vehicles.
- QoS is specified to ($\mu = 500$, $\delta = 200$).
- Some vehicles are designed as destination vehicles for multihop I2V data delivery with inbound delivery QoS, circulating around the road network with their vehicle trajectory.
- The speed of vehicles is generated from a normal distribution of $N(\mu_v, \sigma_v)$ [18], [19]. For simplicity, we set the same speed distribution of $N(\mu_v, \sigma_v)$ in the road networks.
- During simulation, a packet is generated from RSU every 5 seconds. Note that data traffic is low because our target application is the delivery of customized road condition information.
- To evaluate in the same condition, Uniform Placement and Random Placement select the same number of RSUs in Greedy Set-Cover Algorithm.

Through simulation results, our goal is to show that Greedy Set-Cover Algorithm has better performance than other algorithms.

B. Simulation Results

In this section, we report the results of Greedy Set-Cover Algorithm in terms of packet delivery delay, packet delivery cost, and packet delivery ratio. The results are evaluated against Uniform Placement and Random Placement.

Uniform Placement and Random Placement take the vertex set and the required number of RSU. These placements return the selected vertices that represent the intersections of the road network on which RSUs placed. Greedy Set-Cover Algorithm is the implementation of Algorithm 1. The simulation results of these three placements are shown in Fig. 3. At first, we can see that the results satisfy required QoS delivery delay except the case of 100 vehicles in the Fig. 3 (a) and 20MPH in the Fig. 3 (d). Figs. 3 (a), (b), and (c) are simulation results for *Number of Vehicles* parameter. Random Placement's performance becomes dramatically worse as the number of vehicle is greater than 500. Greedy Set-Cover Algorithm and Uniform Placement have similar performance. Greedy Set-Cover is better in range from 300 to 500 and Uniform Placement is slightly better in the other range. Figs. 3 (d), (e), and (f) are simulation results with *Vehicle Speed* parameter. These graphs show that Random Placement becomes dramatically worse as the speed of vehicle

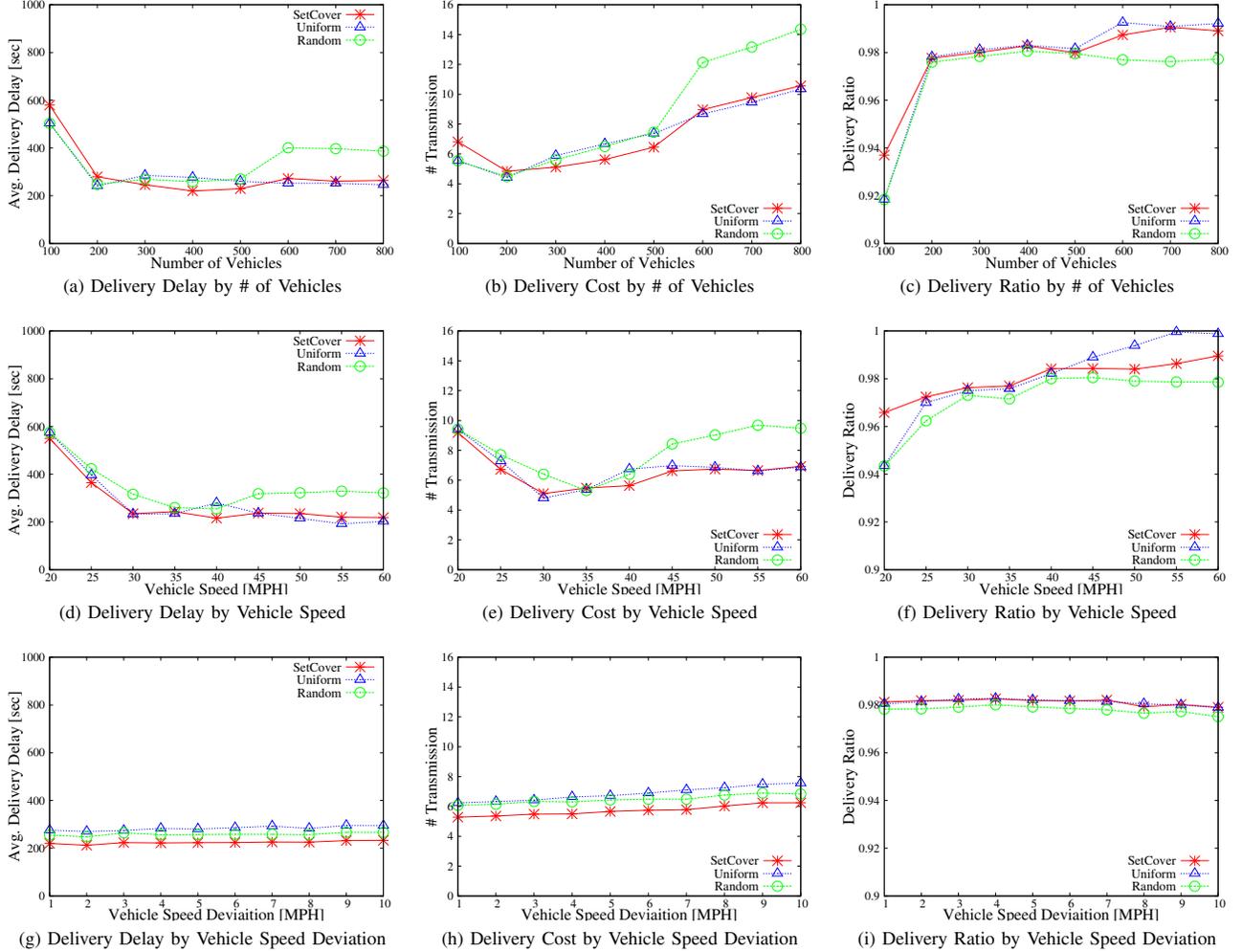


Fig. 3: Simulation Results for Three Placement Algorithms

is bigger than 45MPH . In this case, we can see that Greedy Set-Cover Algorithm has better performance in a lower speed than 45MPH and Uniform Placement has better performance in a higher speed. Figs. 3 (g), (h), and (i) are simulation results with *Vehicle Speed Deviation* parameter. We can see that the influence of speed deviation is weak.

In the simulation results, Greedy Set-Cover Algorithm that we proposed is not always good compared to Uniform Placement. Our analysis for the reason of the above results are as follows:

- Greedy Set-Cover can select a minimal number of intersections. However, it may not select the optimal positions of that number of intersections.
- Network coverage is wider in case of many vehicles or higher vehicle speed. Wider network coverage means that Greedy Set-Cover chooses a point far away from the previously selected points. This can increase the average delivery delay when it is viewed as a whole.

VI. RESEARCH ISSUES

In this section, we consider practical issues for RSU placement as follows:

- Actually, our proposed algorithm performs similarly to uniform placement. Uniform is better in some cases and Greedy Set-Cover is better in other cases. Thus, if we combine both schemes smartly, we will get better performance. This can be implemented by the following two concepts.
 - Traffic-Considered Uniform: We can place RSUs basically uniformly with considering traffic.
 - Set-Cover and Optimizing: We can place RSUs by Greedy Set-Cover, and optimize this result by moving points with uniform distribution.
- In this paper, we consider only inbound data delivery and inbound QoS. We can extend the data delivery for outbound data delivery and outbound QoS.

VII. CONCLUSION

In this paper, we propose a Greedy Set-Cover Road-Side Units (RSU) Placement Algorithm for vehicular networks, providing data delivery QoS in vehicular networks. Nowadays, the popularity of GPS-based navigation system and DSRC communication devices is increasing. Thus, the carry-and-forwarding approach will be used to deliver packets in vehicular networks in cost-effective way not far in the future. Our scheme for RSU deployment will be better with packet forwarding-and-carry approach than the legacy scheme based on only carry, such as α -coverage. As future work, we will design and implement a new Set-Cover algorithm with the advantages of uniform placement.

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