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Data Delivery based on Mobile Roadside Unit and with QoS Guarantee for Vehicular Ad Hoc Networks

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Abstract

The abstract Data delivery in vehicular ad hoc networks (VANETs) has become one of the most challenging problems due to the rapid movement of vehicles and their bounded communication ranges. How to more efficiently transmit the sensing data about the region of interest to AP is discussed in this paper. Previous work hasn't distinguished node types to forward data packet commonly, the delivery ratio and delivery latency is highly possible to reach intolerable dimensions. This paper utilizes the prominent characteristic of buses, and proposes a data forwarding scheme（MUQ） based mobile roadside unit (MU) with quality of service (QoS) guarantee for VANET applications that support both periodic and event-based data reporting. The aim of this paper is to minimize expected minimum delay (EMD) of the packet under the premise of guaranteeing QoS. The performance measures of MUQ are evaluated using simulation. The simulation results indicate the efficiency and availability of MUQ scheme presented in this paper.

Keywords: *Vehicular Ad hoc NETworks (VANETs), Intelligent Transportation Systems (ITS), Mobile roadside Unit(MU),Markov Decision Process(MDP), Quality of Service (QoS)*

1. Introduction

Recent surveys show [1] that the road traffic conditions affect the safety of the population since in Europe around 40,000 people die and more than 1.5 millions are injured every year on the roads. In addition, traffic jams generates huge waste of time and fuel, and cause worsen environmental pollution. Intelligent Transportation Systems (ITS) have been developed that exploit V2V wireless communications and computational technologies to reduce the impact of traffic congestions and promote efficiency of traffic control system in recent decades. Vehicles are used as nodes to form and deform vehicular ad hoc networks (VANETs) in ITS [1-5]. VANETs have been envisioned to be useful in road safety and many commercial applications [1-4]. For example, a vehicular network can be used to alert drivers to potential traffic jams. And it can also be used to propagate emergency warning to drivers behind a vehicle (or incident) to avoid multi-car collisions. As a result, the IEEE standards association has been worked for wireless access in vehicular environments, standardizing Dedicated Short Range Communication (DSRC), such as IEEE 802.11p [6].

Access points (APs) of ITS collect data of the region of interest (ROS) in road networks to realize traffic management, and provide increased convenience and efficiency. It is the greatest important that how to rapidly and reliably transmit the sensing data of ROS to APs. Nevertheless, data delivery has recently emerged one of promising research areas in VANET [3, 4-13], and it is the most one of the most challenging problems in VANET due to the limited radio propagation range of wireless, the multi-hop routing, and the rapid movement of vehicles.

Multi-hop routing in ad hoc network is implemented through cooperative relaying among nodes, rather than through special route equipment. The data forwarding schemes with a stochastic model, such as VADD [5] and MDDV [7] based on traffic statistics which use carry-and-forward approach to forward data packets. [8] Presents a data forwarding scheme to satisfy the user-defined delay bound rather than the lowest delivery delay. To improve the performance of data delivery, TSF [9] and SADV [10] present forwarding packet based on stationary roadside Unit (RSU) at every intersection in road networks. Understandably, the construction cost of infrastructure would be enormous. Taking the present conditions of road network into consideration, they idealize research too much to the achievements are hard to be extensive used. Moreover, can't be a final resolution of the problem for data delivery. For all those existing data delivery approaches, few research works have fully considered QoS for users and have made good use of isomeric vehicular nodes to further improve the performance of data delivery in VANET.

To address these problems in existing research on data delivery, comprehensive analysis of various factors that influence delivery performance. This paper proposes a data delivery scheme (MUQ) based on MU and with QoS guarantee for a real-time, reliable data delivery that MUQ utilizes the prominent characteristic of buses, and uses buses as mobile roadside units (MUs) to forward data. The main contributions of this paper can be summarized as following:

- This paper models a bus overlay network as a probabilistic state–space graph. In the graph, forwarding among MUs is modeled as a probabilistic transition among states.

- To minimize the packet delivery delay from ROS to APs, this paper applies the Markov Decision Process (MDP) to derive optimal decision of forwarding data packet in a probabilistic state–space graph.

- With the state–space graph, we apply the markov decision process to derive the Expected Minimum Delay (EMD) of the packet.

- Applying Bellman equation obtains the optimal strategies for MDP when their values converge.

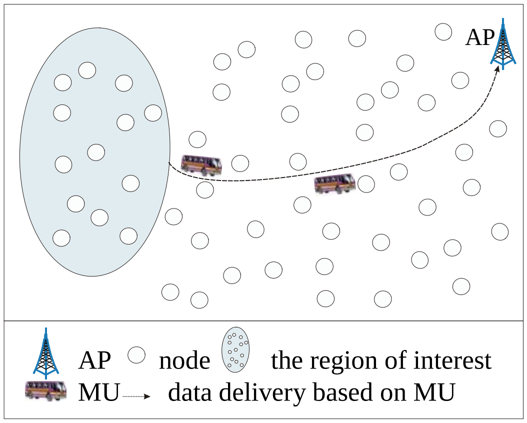

Figure 1. The Architecture of Data Delivery based on MU in VANET

2. Assumptions and Network Model

This paper assumes that vehicles with wireless communication devices (such as the DSRC devices) are used as OBUs participating in VANET, and buses in road networks are installed with GPS-based navigation systems and digital road maps [14, 15]. In the multi-AP road network, this paper assumes that each bus knows other's specified schedules and fixed routes. The architecture of data delivery based on MU is as shown in Figure 1.

In drive-thru networks, vehicles are used as nodes to form and deform the network and can access Internet via APs. This paper models a VANET based on MU for data delivery as a probabilistic state–space graph $G=(S, E)$, where S is the set of states. For example, the state s_{ij} is defined as a 2-tuple $s_{ij}=<b_i,I_j>$, where b_i is one of the i-th bus line, $i=1,2,\cdots,n$. I_j is a section, $j=1,2,\cdots,m$ .To simplify, this paper numbers the subscripts of states, $s_1, s_2, s_3,\ldots$. E is the set of weighted links among states, each link in G is a possible state transition which is associated with a delay d and a maximal transition probability p .For example, link e_{ij} is a 2-tuple $e_{ij}=<d_{ij}, p_{ij}>$, e_{ij} represents that the probability of state transition from the state s_i to s_j is p_{ij} ,and the delay of it is d_{ij} ,as shown in Figure 2.

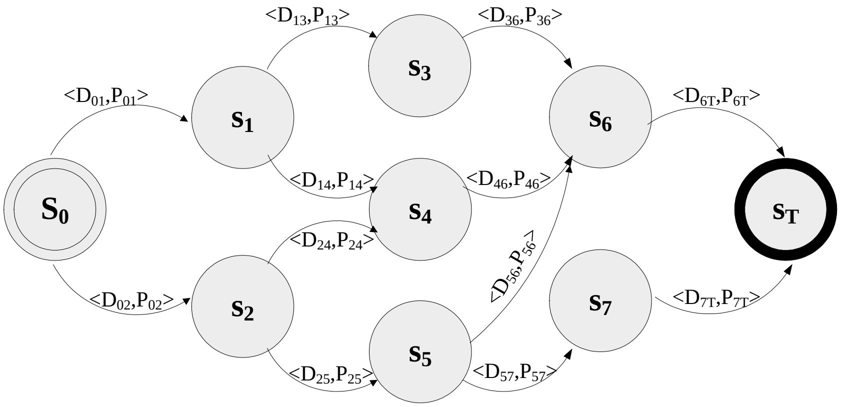

Figure 2. A Probabilistic State Space Graph

3. Problem Formulation

3.1. Description of Data Delivery based on MU Problem with QoS Guarantee (MUQ)

In big and medium sized cities, buses have the following features: denseness trajectories, regular routes, predicable mobility, *etc*. In the multi-AP road network, each bus knows other's specified schedules and fixed routes. To improve the performance of data delivery, this paper utilizes buses on regular routes as mobile roadside units (MUs), and adopts the carry-and-forward approach to forward data packet from the region of interest (ROS) to sink nodes (*e.g.*, AP) as shown in Figure 1. In order to solve the minimizing delay problem, this paper models forwarding among MUs as probabilistic transition among states in a probabilistic state–space graph as shown in Figure 2. With the state–space graph, this paper applies the markov decision process (MDP) to derive the expected minimum delay (EMD) of the packet (seen in Section 4).

3.2. Formulation of MUQ Problem

This paper formulates the data delivery in vehicular ad hoc network as follows: Given a road network with APs, our goal is to rapidly and reliably transmit the sensing data ROS to an AP with an expected minimum packet delivery delay while satisfying the user-required packet delivery probability. Satisfying Quality of Service (QoS) requirements (*e.g.*, bandwidth and delay constraints) for the different QoS based applications of VANETs raises significant challenges. The data forwarding scheme proposed is to minimize the packet delivery delay with QoS guarantee constraints. QoS constraint in this paper as follows:

$$P_R \geq P_Q \tag{1}$$

In (1), the probability of delivery ratio P_R represents the probability that the packet is transmitted from ROS to AP before the packet's Time-To-Live (TTL), P_Q is a requirement of the delivery reliability. This paper presents a data delivery scheme based on MUs and with QoS guarantee (MUQ) that it uses MUs to forward packets. To minimizes delivery delay while satisfying QoS requirements, objective functions are formulated as follows:

$$\min\{E(D_S^D)\} \text{ subject to } P_R \geq P_Q \tag{2}$$

In (2), $\mathrm{D}_\mathrm{S}^\mathrm{D}$ represents the packet's delivery delay from ROS to the target AP subject to a reliability constraint. If the vehicular traffic in road networks follows the Poisson arrival model, the distributions vehicle delay follow the Gamma distributions such that $\mathrm{D}^\mathrm{V} \sim \Gamma(\alpha_\mathrm{v}, \beta_\mathrm{v})$ [16].

We model the vehicle delay from one position to another position in a given road network. Give the road network graph G, the travel time for edge $\mathrm{e}_\mathrm{i} \in E(G)$ is modeled as the Gamma distribution of $\mathrm{d}_\mathrm{i} \sim \Gamma(\alpha_i, \beta_\mathrm{i})$;note that the travel time distribution for each road segment can be obtained through vehicular traffic measurement and is usually considered the Gamma distribution [17, 18].

The parameters α_i and β_i of the Gamma distribution are computed with the mean travel time $\mathrm{E}[\mathrm{d}_\mathrm{i}]$ and the travel time variance $\mathrm{Var}[\mathrm{d}_\mathrm{i}]$ using the relationship among the mean $\mathrm{E}[\mathrm{d}_\mathrm{i}]=\alpha_i\beta_i$, the variance $\mathrm{Var}[\mathrm{d}_\mathrm{i}]=\alpha_i\beta_i^2$ for $\mathrm{d}_\mathrm{i}, \alpha_i, \beta_i > 0$ [16] as follows:

$$\beta_i = \frac{\mathrm{Var}[\mathrm{d}_\mathrm{i}]}{\mathrm{E}[\mathrm{d}_\mathrm{i}]} = \frac{\sigma_i^2}{\mu_i} \tag{3}$$

$$\alpha_i = \frac{\mathrm{E}[\mathrm{d}_\mathrm{i}]}{\beta_i} = \frac{\mu_i^2}{\sigma_i^2} \tag{4}$$

This paper assumes that the travel times of edges consisting of the trajectory are independent, the mean and variance of the vehicle delay distribution can be computed as follows:

$$\mathrm{E}[\mathrm{D}^\mathrm{v}] = \sum_{\mathrm{i}=1}^{\mathrm{M}} \mathrm{E}[\mathrm{d}_\mathrm{i}] = \sum_{\mathrm{i}=1}^{\mathrm{M}} \mu_\mathrm{i} \tag{5}$$

$$\mathrm{Var}[\mathrm{D}^\mathrm{v}] = \sum_{\mathrm{i}=1}^{\mathrm{M}} \mathrm{Var}[\mathrm{d}_\mathrm{i}] = \sum_{\mathrm{i}=1}^{\mathrm{M}} \sigma_\mathrm{i}^2 \tag{6}$$

With $\mathrm{E}[\mathrm{D}^{\mathrm{v}}]$ and $\mathrm{Var}[\mathrm{D}^{\mathrm{v}}]$, the parameters α_{v} and β_{v} of the Gamma distribution are computed. Multi-hop routing in ad hoc network is implemented through cooperative relaying among nodes, namely carry-and-forward approach. The packet's delivery delay depends mainly on carry-delay by MUs, and forward-delay can be negligible because carry-delay is 4-5 orders of magnitude larger than it.

$$\begin{aligned} P_R = \mathrm{P}(\mathrm{D}_{\mathrm{S}}^{\mathrm{D}} \le \mathrm{X}) &= \int_0^{\mathrm{X}} g(t)dt \\ &= \int_0^{\mathrm{X}} g(\mathrm{t};\alpha_{\mathrm{v}},\ \beta_{\mathrm{v}})dt \quad \text{for } \alpha_{\mathrm{v}} > 0 \end{aligned} \tag{7}$$

In (7), where $g(t)$ is the PDF of vehicle delay v, and X is the packet's Time-To-Live (TTL); Note that the packet's lifetime TTL indicates the real-time requirement of data, that is, since the packet is discarded after TTL, the probability portion is zero after TTL.

In (2), $E(D_S^D)$ represents the packet's expected minimum delay (EMD) from ROS to the target AP in VANET. In next section, this paper applies the MDP to derive the EMD of each data packet in the state–space graph.

4. Expected Minimum Delay (EMD)

Forwarding decision in states where the packet delivery delays are partly probabilistic and partly under the control of a decision maker in data delivery process. The crucial problem of the packet's EMD is whether or not forwarding and forwarding the packet to which MU. In this section, this paper models the forwarding data process as MDP, use Bellman equation to solve MDP, the values associated with the states in the functions are updated iteratively and until they converge.

4.1. MARKOV Decision Process Model (MDP)

The MDP [19] provides a mathematical framework for modeling decision making in situations where outcomes are partly random and partly under control of the decision maker. MDP is a generalized Dijkstra's algorithm for probabilistic graphs.

This paper reformulates a variation of MDP as a 5-tuple $\mathrm{M}{=}{<}\mathrm{S},\mathrm{A},\Gamma,\mathrm{D},\mathrm{S}_{\mathrm{T}}{>}$. S is a finite set of states, state $\mathrm{s} \in S$, $\mathrm{s}{=}{<}\mathrm{b}_{\mathrm{i}},\mathrm{I}_{\mathrm{j}}{>}$, $\mathrm{i}=1,2,\cdots,\mathrm{n}$, $\mathrm{j}=1,2,\cdots,\mathrm{m}$ .At any given time, the system can be at only one state in the set of all states. A is a finite set of actions (alternatively, As is the finite set of actions available from state s).Only one action is allowed to take effect at a time. Γ is a transition probability function, $\Gamma_{\mathrm{a}}(s,s')$ represents the probability of transiting from state s to state s' when applying action a , a transmitting probability according to the priority and the bus-to-bus contact probability to computer. Evidently, $\sum_{s' \in \mathrm{S}} \Gamma_{\mathrm{a}}(s,s')=1$. $\mathrm{D}(\mathrm{s},\mathrm{s}')$ is the delay of transiting from state s to state s' .As shown in Figure 2, $\mathrm{D}(\mathrm{s}_5,\mathrm{s}_7)=\mathrm{D}_{5,7}$. S_{T} is the set of all goal states.

The result of applying MDP is a value function that gives the expected minimum total delay it takes to transit from to any goal state $\forall s_T$. S_{T} is a goal state set, $\mathrm{S}_{\mathrm{T}} = \{s_T | s_T = {<}\mathrm{b}_{\mathrm{i}},\mathrm{I}_{\mathrm{j}}{>} \text{ IFF } \mathrm{I}_{\mathrm{j}} \in \mathrm{E}_{\mathrm{T}} \text{ and } {<}\mathrm{e}_{\mathrm{jt}},\mathrm{e}_{\mathrm{T}}{>} \in \mathrm{R}_{\mathrm{b}_{\mathrm{i}}}\}$,where E_{T} is neighbor node set of the target AP .

4.2. Deriving EMD using MDP

In this section, this paper describes how to derive EMD using MDP. Value iteration [20] solves MDP by iteratively updating the value functions in $\gamma^*(\mathrm{s})=\min\limits_{a\in \mathrm{A(s)}}\sum\limits_{\mathrm{s}'\in \mathrm{S}}\{\Gamma_{\mathrm{a}}(s,s')\times[\mathrm{D(s,s')}+\gamma^*(s')]\}$ for all states until their values converge. By applying value iteration to Bellman equation, the optimal strategies $\pi^*(\mathrm{s})=\arg\min\limits_{a\in \mathrm{A(s)}}(\Gamma_{\mathrm{a}}(s,s')\times[\mathrm{D(s,s')}+\mathrm{V}^*(s')])$ are derived for MDP when their values converge.

In each round of the iteration t+1, based on the resulting values $\mathrm{T_a}(s,s')$ from the previous iteration t, the value $\gamma_{\mathrm{t+1}}(s)$ of each state $s\notin \mathrm{S_G}$ is updated by choosing an action $a\notin \mathrm{A_s}$ such that $\gamma_{\mathrm{t+1}}(s)$ is minimized. In the right side of (8), when taking an action a, the value of state s is the expected delay $\mathrm{D(s,s')}+\gamma_{\mathrm{t}}(s')$ weighted by the probability of the transition from state s to its next state s'

$$\gamma_{\mathrm{t+1}}(\mathrm{s})=\min_{a\in \mathrm{A(s)}}\sum_{\mathrm{s}'\in \mathrm{S}}\{\mathrm{T_a}(s,s')\times[\mathrm{D(s,s')}+\gamma_{\mathrm{t}}(s')]\} \tag{8}$$

For every state s, the difference between values $\gamma_{\mathrm{t+1}}(s)$ and $\gamma_{\mathrm{t}}(s)$ is less than some threshold value, the value functions of all states are considered to converge. The values of the states are properly initialized in (9).

$$\gamma_0(s)=\min_{a\in A(s)}\{\min_{s':T_a(s,s')>0}\gamma_0(s')\} \tag{9}$$

The current state is s : the current bus is $\mathrm{b_c}$ which possible forward packet to $\mathrm{b_1}$, $\mathrm{b_2}$ or $\mathrm{b_3}$,transmit to s_1 , s_2 or s_3 .If $\gamma(s_1)<\gamma(s_2)<\gamma(s_3)$,then the order of priority of state transition is $\{s_1,s_2,s_3\}$,which means that the delivery delay of s_1 is minimum and the delivery delay of s_3 is maximum, so $\mathrm{b_c}$ (the current state is s)will forward packet to $\mathrm{b_1}$ (transit to s_1) whenever possible and will forward packet to $\mathrm{b_3}$ (transit to s_3) only when the forwarding packet to neither $\mathrm{b_1}$ nor $\mathrm{b_2}$ (the transition to neither s_1 nor s_2) is possible. In this paper, we assume that $\mathrm{p_1^T}$, $\mathrm{p_2^T}$ and $\mathrm{p_3^T}$ is the transition probability from s to s_1 , s_2 , s_3 ,respectively. $\mathrm{p_1^T}+\mathrm{p_2^T}+\mathrm{p_3^T}=1$, and $\mathrm{p_1^T}=p_{\mathrm{c1}}$, $\mathrm{p_2^T}=(1-\mathrm{p_1^T})\times p_{\mathrm{c2}}$, $\mathrm{p_3^T}=(1-\mathrm{p_1^T}-\mathrm{p_2^T})\times p_{\mathrm{c3}}$,where p_{c1} , p_{c2} and p_{c3} represents the contact probability of $\mathrm{b_1}$ and $\mathrm{b_1}$, $\mathrm{b_2}$, $\mathrm{b_3}$ s_3 ,respectively. $\mathrm{p_1^T}$, $\mathrm{p_2^T}$ and $\mathrm{p_3^T}$ are the weights of $T_a(s,s')$, $s'=s_1,s_2,s_3$.

5. Performance Evaluation of MUQ

In this paper, we model a road network in detail using SUMO simulator and process data based on MATLAB. In this section, this paper evaluates the performance of MUQ proposed by simulator.

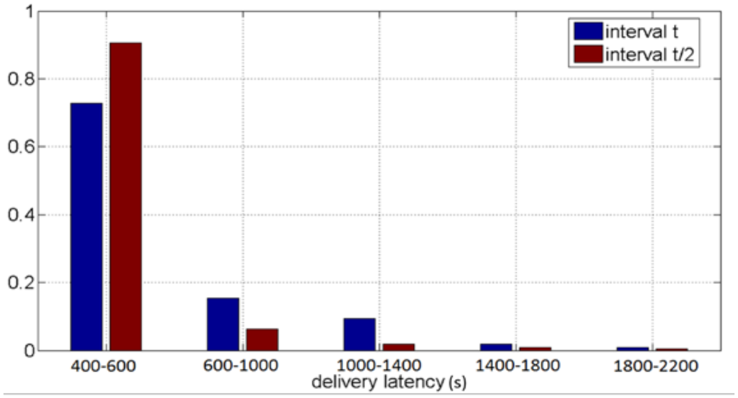

Figure 3. EMD and the Percentage of Minimum Delivery Delay of MUQ

To derive the Expected Minimum Delay (EMD) of the packet, this paper adopts MDP to probabilistic forward packet based MU while satisfying the required packet delivery probability. Previous work [11] has proved that the value iteration and the extended TVI guarantee that the values of the states converge to EMDs. This paper compares the forwarding behaviors of MUQ while the departure interval of buses is □t and □t/2 , respectively. Probability distribution of delivery latency as shown in Figure 3, The statistical results indicate that minimum delivery delay occupies a little more than 70 percent while the departure interval of buses is □t and the percentage of it is up to no less than 90 percent while□t/2 while □t/2 . EMD is 681.67s while the departure interval of buses is □t and it is 523.39s.

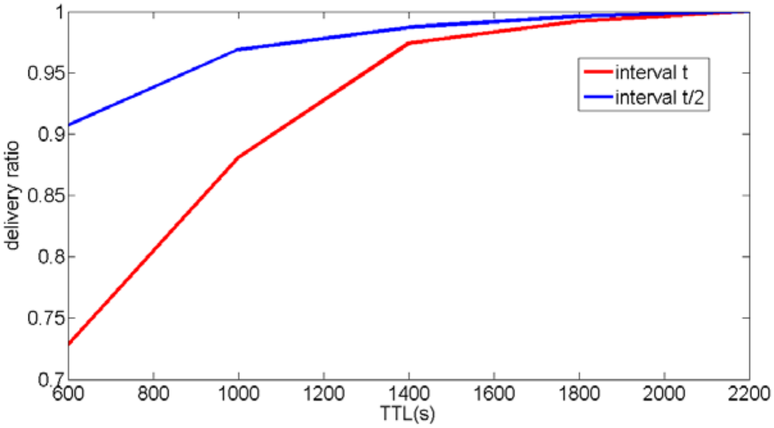

Figure 4. TTL vs. Delivery Ratio

As shown in Figure 4, delivery ratio varies with TTL. The experimental results indicate that delivery ratio increases with the increase of TTL. Higher delivery ratio can be achieved by reducing real-timeliness. In actual application, it often takes the trade-off between price and quality.

To improve the performance of data delivery under the premise of guaranteeing QoS, this paper models forwarding among MUs as probabilistic transition among states in a probabilistic state–space graph. With the state–space graph, this paper applies the markov decision process to derive the Expected Minimum Delay (EMD) of the packet. The jitter of delay while the departure interval of buses is □t/2 .is much less than the jitter while the departure interval of buses is □t . The experimental results indicate that departure interval is less and the performance of data delivery is better.

6. Conclusion

The approaches of data delivery in VANET can be classified into two categories: No Static-RSU Assisted (NSUA) and Static-RSU Assisted or Static-RSU based (SUA). (1) NSUA: For example, VADD [5] and MDDV [7] try to forward data using in-situ next carriers, and are No Static-RSU Assisted. The approaches have such high standard deviation (STD) estimation errors that the delivery ratio and delivery latency is possible to reach intolerable dimensions. (2) SUA: TSF [9] and SADV [10] present to forward packet based on stationary roadside Unit (RSU) at every intersection at the road networks. Understandably, the construction cost of infrastructure would be enormous. Under present conditions of road network, they idealize research too much to the achievements are hard to be extensive used. Moreover, can't be a final resolution of the problem.

Based on this analysis, this paper uses buses on regular routes as mobile roadside unit to assist data delivery, and to shorten transmission delay under the prerequisite of ensuring QoS, MUQ scheme is presented. MUQ is established under very few assumption conditions that it can combine the advantages of both NSUA and SUA. Moreover, it is close to real environment, therefore it is suitable for ROS-AP data delivery in vehicular ad hoc network and is more extensive applied under a variety of vehicular traffic conditions. Through theoretical analysis and extensive experiments, it is shown the effectiveness of our design provides for data forwarding in vehicular ad hoc network.

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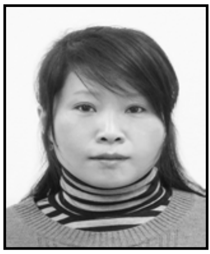

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