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차량 네트워크에서 예측 기반의 안정적 데이터 포워딩 기법

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Prediction-Based Reliable Data Forwarding Method in VANET

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요 약

VANET은 안전 운전 및 효율적인 교통 환경을 제공하는 다양한 ITS 서비스 실현을 위한 기술 중 하나이다. VANET에서의 데이터 전송은 노드들의 높은 이동성으로 인하여 복잡성을 야기한다. 본 논문에서는 VANET에서 패킷을 안정적이고 적시에 전달하는 새로운 포워딩 기법을 제안한다. 제안된 기법은 차량 만남을 예측하기 위해 트래픽 통계를 이용하고, 만남 장소에서의 성공적인 무선 전송 확률을 고려함으로써 포워딩 결정을 최적화 한다. 시뮬레이션을 통하여 제안된 포워딩 기법이 VANET 환경에서 신뢰성있는 데이터 전송을 달성함을 확인하였다.

Key Words : 802.11p, WAVE, VANET

ABSTRACT

Vehicular Ad hoc Network (VANET) is one of technologies to realize various ITS services for safe driving and efficient traffic control. However, data delivery in VANETs is complicated due to high mobility and unreliable wireless transmission. In this paper, we develop a novel forwarding scheme to deliver packets in a reliable and timely manner. The proposed forwarding scheme uses traffic statistics to predict the encounter of two vehicles, and optimize its forwarding decision by taking into consideration the probability of successful transmission between them at the encounter place. We evaluate our scheme through simulations and show that our proposed scheme provides reliable data delivery in VANETs.

Ⅰ. Introduction

The convergent technology based on information and communication engineering suggests a new paradigm of Intelligent Transport System (ITS) to combine information technology (IT) with automotive technology. ITS aims to provide necessary foundation for realizing efficient traffic system and various services such as Advanced Public Transportation system (APTS) and Advanced Traffic Management System (ATMS). Many developed countries have already recognized ITS as

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national industrial infrastructure to advance traffic systems. Among many ITS technologies, wireless communication is one of the key elements. Reliable and timely information exchange is critical for safety-critical applications.

Vehicular Ad hoc Network (VANET) is a way to realize smart ITS for safe driving and efficient traffic management[1]. VANET is a wireless ad-hoc network that consists of vehicles, where each vehicle is assumed to have wireless transceiver and acts as a network node[2]. Vehicular communications enable the users to communicate to roadside infrastructure or to each other for safety and transportation efficiency.

Routing protocols[2,3] in VANET have been studied extensively, especially based on mobile ad hoc networks (MANET). Generally, mobile ad hoc routing protocols aim to achieve reliable packet delivery and low delivery delay, with minimal communication overhead and network resource. MANET routing protocols can be largely classified into two categories: proactive routing and reactive on-demand routing[5]. The proactive routing protocol calculates a route from one node to all other nodes in advance. Representative proactive protocols include Destination-Sequenced Distance-Vector (DSDV) and Optimized Link State Routing (OLSR). In contrast, the reactive routing protocol discovers a route only when it is explicitly requested. Dynamic Source Routing (DSR), and Ad hoc On Demand Distance Vector (AODV) are most widely used.

Although many routing protocols that have been developed in MANET, most of them do not work well in VANET. It has been shown that many previous routing protocols for MANETs perform poorly in VANETs[6,7]. One of the main problems is that the previous routing protocols fail to achieve stable route information. The high vehicle mobility causes frequent route failures. It leads to many packet drops and significant amount of overhead for route recovery, and low performance in delivery ratio and delay.

Several location-based routing protocols, which are known to be useful in VANET, are proposed to overcome the problem. Given GPS and navigation infomation, location-based routing protocols perform greedy forwarding based on the position of the source, the destination, and neighbor nodes. This improves network efficiency by reducing heavy overhead and long delay. However, overhead of location service, inaccurate location information of nodes due to high mobility, and unreliable packet forwarding due to high node density are the weaknesses. High node mobility not only changes connectivity of individual vehicle but also node density, which impacts on the quality of wireless communication: severe interference in high node density and poor connectivity in low node density.

In this paper, we develop a reliable and timely data forwarding scheme. The proposed forwarding scheme exploits traffic statistics to predict vehicle encounters, and optimizes forwarding decision by taking into consideration the quality of wireless communications.

This paper is organized as follows. Section 2 summarizes related work. Section 3 provides the system model. Section 4 explains our data forwarding scheme, and Section 5 evaluates its performance. Finally, Section 6 concludes this paper.

Ⅱ. Related Work

In VANETs, many data forwarding schemes use the carry-and-forward approach, where a vehicle carries message until it can transmit the message to the destination or to a relay node. Traffic information (e.g., traffic density and average vehicle speed per road segment) is commonly used to guide the forwarding operation.

Greedy Perimeter Stateless Routing (GPSR) has been proposed to actively utilize wireless communications for forwarding[8]. In this protocol, a vehicle can transmit its packet to a neighboring vehicle that are geographically closer to the destination. In the meantime, if the vehicle with the packet is the closest to the destination among those in its neighbors, while it cannot directly transmit the packet to the destination yet, GPSR switches to its mode such that the packet can be forwarded following the right-hand rule (rather than the shortest distance). GPSR outperforms DSR in many aspects[9] in terms of packet delivery ratio and overhead.

Greedy Perimeter Coordinator Routing (GPCR) is another routing scheme in VANET[10]. It assumes that vehicles within a road segment naturally consist of a planar graph, and in this case, a greedy forwarding would be sufficient in the forwarding. In GPCR, packets are forwarded through wireless communications through the road segmen, and a routing decision is made at a junction. It has been shown that GPCR outperforms GPSR when the route has a larger number of hops.

Geographic Source Routing (GSR) has been designed for city environments[11]. A vehicle with a packet starts a route discovery procedure called Reactive Location Service (RLS) and can obtain the position of the destination. Once it obtains the location information, packets are forwarded to the intermediate vehicle closest to the destination. However, the route discovery does not perform well in light-traffic vehicular networks.

Vehicle-Assisted Data Delivery (VADD) makes use of a stochastic model based on vehicle traffic statistics[12]. It aims to reduce packet delivery delay from a mobile source to stationary destination. Static-node-assisted Adaptive Data Dissemination protocol for Vehicular networks (SADV) is a forwarding scheme with help of static relay nodes that are placed at intersections[13]. The relay nodes contribute to achieve predictable data delivery delay. Both VADD and SADV utilize traffic information such as traffic density and average vehicle speed for better forwarding operations. Although they perform well in dense vehicular networks, they often suffer from poor performance in sparse networks.

Trajectory-Based Data Forwarding (TBD) is data forwarding scheme for V2I communications[14]. Utilizing vehicular traffic statistics and vehicle trajectory information, TBD improves end-to-end delivery delay. For I2V (Infrastructure-to-Vehicle) communications, the authors of [15] have proposed Trajectory-based Statistical Forwarding (TSF). TSF speculates the location where the destination vehicle will pass by and forwards the packet to the location, where the packet delivery delay can be minimized. TBD and TSF require vehicle trajectory information from GPS-based navigation system. Although these protocol overcome some limitations of VADD and SADV (e.g., prone to errors in sparse networks), they do not consider the quality of wireless links that highly depend on vehicle traffic.

Ⅲ. System Model

In this section, we describe the system model and provide the motivation. We assume that each vehicle has a fixed travel trajectory and knows the traffic statistics of roads. The latter is based on the fact that traffic information is becoming popular[16], as well as they are commonly assumed in the literature[14,15]. When a vehicle has a packet to send, it needs to decide whether it carries the packet or forward the packet for relay.

We describe the network environment in consideration for vehicle-to-vehicle data forwarding in road networks. We consider a VANET where vehicles in proximity can communicate with each other through wireless interface, e.g., WAVE (Wireless Access in Vehicular Environment). We assume that there are two different types of vehicles in the network: private vehicles and public vehicles, which are based on that the vehicles are soon required to equip a WAVE device and the subscription for Internet service will remain optional.

1) Private Vehicle has limited communication capability. It can communicate with nearby vehicles, and is not connected to the Internet.

2) Public Vehicle can communicate with nearby private vehicles, and is also connected to the Internet through Wide Area Network (WAN). For private vehicles, it can play the role of a backhaul node to the Internet and serves the packets from the private vehicles. Public vehicles operate following a predetermined route, which is known a priori.

When a private vehicle has a packet for the Internet service, it tries to reach one of the available public vehicles, either by directly carrying the packet to the public vehicle or by transmitting the

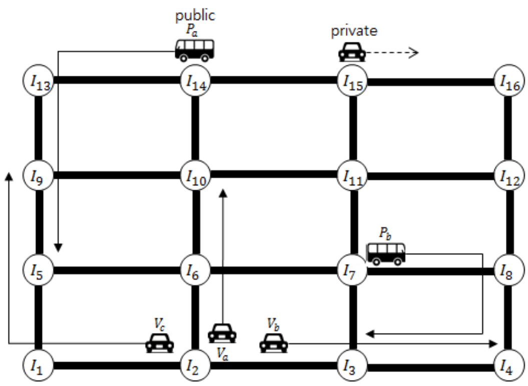

Fig. 1. Vehicular network with two types of vehicles (private and public vehicle).

packet for relay to another private vehicle that will encounter the public vehicle. To this end, when two private vehicles are within the communication distance, they exchange necessary information including the expected time to encounter a public vehicle.

For the information exchange, each vehicle equips a WAVE communication device and can communicate with each other in proximity. WAVE is the standard protocol stack for vehicular communications, and adopts Carrier Sensing Medium Access (CSMA) Collision Avoidance (CA) as in the IEEE 802.11 protocols[17]. There is a possibility that multiple vehicles that are close to each other transmit simultaneously, in which case, a collision occurs and all the involved transmissions fail. Upon collision, vehicles may retransmit the packet for reliable delivery. However, since the vehicles move and the transmission range is limited, the maximum number of retransmissions is bounded.

There have been works[12,14,15] that tried to achieve timely packet delivery in VANETs under the assumption of no packet loss. However, in dense areas, e.g. city area, packet loss due to collision is unavoidable under the standard WAVE CSMA/CA operations. In high vehicle density, multiple vehicles are likely to attempt to transmit at the same time, and it is challenging to deliver packets in a reliable manner. We consider the forwarding problem in urban areas, where the packet loss event is relatively common.

We consider a vehicular network with a map (i.e., roads and intersections), the set V of the private vehicles, and the set P of the public vehicles. The public vehicles (e.g., buses) are connected to the Internet through WAN. We number all the intersections on the map. For example, in Fig. 1, we let I_i denote intersection i and let $L_{i,j}$ denote the road segment identified by two intersections I_i and I_j. Suppose that the source $V_a \in V$ generates a packet. Depending on its path, it may or may not encounter a public vehicle. Further, even if it encounters a public vehicle, it may fail to transmit the packet if they encounter in a crowded area. To deliver the packet in a reliable and timely manner, it could be possible for the source to transmit the packet to another private vehicle $V_b \in V$ and to use it as a relay vehicle to deliver the packet to a public vehicle. We note that anycast is in consideration and the packet can be delivered to any public vehicle. Fig. 1 shows an example of the operation. Private vehicle $V_b \in V$ will encounter public vehicle $P_b \in P$ on road segment $L_{3,4}$ (between intersections I_3 and I_4) and private vehicle $V_c \in V$ will encounter public vehicle $P_a \in P$ on road segment $L_{5,9}$. If road segment $L_{3,4}$ is crowded (while road segment $L_{5,9}$ is relatively empty), V_a transmits the packet to V_c, which can reliably deliver the packet to public vehicle P_a. In the paper, we will provide a quantitive measure to determine whether a road segment is crowded or not.

Motivated by this, we design a novel forwarding scheme that delivers packets in a reliable and timely manner accounting for the vehicle density. To this end, we estimate expected encounter time, and the probability of successful transmission at encounter place. For the former, we make use of previous results, which are included for completion. Our main contribution includes the estimation of the probability of successful transmission in VANET, and the decision procedure for packet transmission based on the probability.

Ⅳ. Probabilities of Vehicle Encounter and Successful Transmission

Given a VANET with anycast to public vehicles, our goal is to make a forwarding decision for reliable and timely packet delivery. To this end, we calculate the encounter probability of two vehicles as in [18], and develop a novel estimation method for the probability of successful packet transmission under CSMA/CA.

4.1 Encounter probability

Given the predetermined paths (or trajectories) of vehicles, we can estimate the encounter probability of the two vehicles traveling in their opposite direction. Suppose that the trajectories of two vehicles overlap on road segment $L_{i,j}$: one vehicle travels from intersection I_i to I_j, and the other travels from intersection I_j to I_i. The probability that two vehicle encounters on road segment $L_{i,j}$ can be estimated by estimating the time when they arrive at intersection I_i. To this end, we start with the travel time of a vehicle on a road segment.

It has been shown that the travel time over a road segment follows the Gamma distribution $\Gamma(\kappa,\theta)$, where is the shape parameter and is the scale parameter[15,18]. Thus, the travel time (or link travel delay) $d_{i,j}$ of a vehicle through road segment $L_{i,j}$ is modeled as $\Gamma(\kappa_{i,j},\theta_{i,j})$, where the parameters $\kappa_{i,j}$ and $\theta_{i,j}$ can be estimated by using the mean $E[d_{i,j}]=\mu_{i,j}$ and the variance $Var[d_{i,j}]=\sigma_{i,j}^2$ of the link travel delay as follows[20]:

$$\theta_{i,j}=\frac{Var[d_{i,j}]}{E[d_{i,j}]}=\frac{\sigma_{i,j}^2}{\mu_{i,j}}, \tag{1}$$

$$\kappa_{i,j}=\frac{E[d_{i,j}]}{\theta_{i,j}}=\frac{\mu_{i,j}^2}{\sigma_{i,j}^2}. \tag{2}$$

The traffic statistics of $\mu_{i,j}$ and $\sigma_{i,j}^2$ are assumed to be available through the navigation system or the digital map[21].

The result can be extended to the travel delay over a sequence of road segments, i.e., a path. Consider a set N of road segments that is a partial sequence of the vehicle's trajectory. Under the assumption that the travel times across multiple road segments are independent, the end-to-end delay D (over path N) also follows the Gamma distribution $\Gamma(\kappa_D,\theta_D)$ where the parameters κ_D and θ_D are calculated using the mean $E[D]$ and the variance $Var[D]$ as in (1) and (2). From the independency of the travel times over road segments, $E[D]$ and $Var[D]$ can be obtained by summing the means and the variances of each link's travel time along the path as

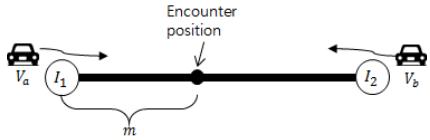

Fig. 2. Two vehicles encountering on road segment $L_{1,2}$.

$$E[D]=\sum_{i\in N}E[d_i]=\sum_{i\in N}\mu_i, \tag{3}$$

$$Var[D]=\sum_{i\in N}Var[d_i]=\sum_{i\in N}\sigma_i^2. \tag{4}$$

We now estimate the encounter probability from the expected travel time over path. We consider two private vehicles V_a and V_b, both of which travel through road segment $L_{1,2}$ between two intersections I_1 and I_2 as shown in Fig. 2. They could be also a public vehicle. Suppose that the current time is time 0, and let $T_{a,1}$ and $T_{a,2}$ be the time when V_a arrives at I_1 and at I_2, respectively. Similarly let $T_{b,1}$ and $T_{b,2}$ be the time when V_b arrives at I_1 and at I_2, respectively. Then, the probability that the two vehicles encounter on $L_{1,2}$ can be written as

$$\begin{aligned}&P(V_a \text{ and } V_b \text{ encounter on roadsegment } \mathrm{L}_{1,2})\\&=P(T_{a,1}\le T_{b,1}\cap T_{a,2}\ge T_{b,2}).\end{aligned} \tag{5}$$

Let $d_{1,2}$ be the link travel delay for $L_{1,2}$. Then, the link arrival time $T_{a,1}$ and the link departure time

$T_{a,2}$ satisfy that $T_{a,2}=T_{a,1}+d_{1,2}$. Similarly, letting $d_{2,1}$ be the link travel delay for $L_{2,1}$, we also have $T_{b,1}=T_{b,2}+d_{2,1}$. Note that $d_{1,2}$ and $d_{2,1}$ follow the Gamma distribution, and the summation of two independent processes with the Gamma distribution is another Gamma distribution with the sum of their means and variances. Thus, we approximate the departure time $T_{a,2}$ and $T_{b,1}$ as $T_{a,2}=T_{a,1}+t_{1,2}$, and $T_{b,1}=T_{b,2}+t_{2,1}$, where $t_{1,2}=E[d_{1,2}]$ and $t_{2,1}=E[d_{2,1}]$. From (5), we obtain:

$$\begin{aligned}&P(V_a \text{and } V_b \text{ encounter on road segment } \mathrm{L}_{1,2})\\&=P(T_{a,1}\le T_{b,1}\le T_{a,1}+t_{1,2}+t_{2,1}).\end{aligned}\tag{6}$$

Let $f(x)$ and $g(y)$ denote the probability density function (PDF) of Gamma random variables for $T_{a,1}$ and $T_{b,1}$, respectively[20]. Then (6) can be calculated as

$$\begin{aligned}&P(V_a \text{and } V_b \text{ encounter on road segment } \mathrm{L}_{1,2})\\&=\int_0^{\infty}\int_x^{x+t_{1,2}+t_{2,1}} f(x)g(y)\,dy\,dx.\end{aligned}\tag{7}$$

We can also calculate the expectation of the encounter time between two vehicles. From Fig. 2, suppose that the encounter position is m meters away from I_1, the mean travel speed from I_1 to I_2 is $v_{1,2}$, and the mean travel speed from I_2 to I_1 is $v_{2,1}$, we have the encounter time T_e as $m=(T_e-T_{a,1})v_{1,2}=(T_{b,1}-T_e)v_{2,1}$. Therefore,

$$T_e=\frac{T_{a,1}v_{1,2}+T_{b,1}v_{2,1}}{v_{1,2}+v_{2,1}}.\tag{8}$$

In addition to the encounter probability (7) and the expected encounter time (8), we need to calculate the probability of successful packet transmission, which will be directly used to make the routing decision.

4.2 Successful transmission probability

We assume that each vehicle “periodically” broadcasts a beacon message to disseminate its location and other information. Once a vehicle successfully identifies the other through the beacon, the two vehicles can exchange the data packet through a separate high-rate channel. Hence, we focus on the probability of successful transmission of the beacon messages. The WAVE protocol that is standardized as the IEEE 802.11p uses the distributed coordinated function (DCF) of IEEE 802.11 for the medium access. Let σ denote the slot time for the carrier sensing and the timer granularity (e.g., $\sigma=13us$ for IEEE 802.11p)[22]. If multiple vehicles attempt a transmission of beacon message in the same time slot, their signals will collide and none of the transmissions will be successful.

We start with a brief overview the operation of the IEEE802.11p CSMA/CA medium access control protocol. Before transmitting a packet, the vehicle ensures idle medium through the carrier-sensing functionality. To elaborate, a backoff timer set to a random integer value in [0, W] is used. The timer counts down only when the channel is idle, and the vehicle attempts to transmit when the timer becomes 0. We do not consider the exponential backoff that is widely used in the case of multiple collisions. The timer counts down by one per time slot, only when the medium is idle. If the medium is busy, the timer freezes. When the timer expires, the vehicle occupies the channel by transmitting the beacon. Once the vehicle grabs the channel and transmits the beacon, the other vehicles will freeze their backoff timer during the transmission time. Let L denote the fixed time duration for a beacon transmission. We denote the beacon waiting in the buffer (due to backoff) by pending beacon, and denote the vehicles with a pending beacon by contending vehicle. All contending vehicles listen to the medium for idle channel, and will transmit a beacon when their time expire. Hence, to calculate the probability of success transmission, estimating the number of contending vehicles is crucial since it directly impacts the probability of simultaneous beacon transmissions. Let N_c denote the expected number of contending vehicles. We note that estimating the expected number N_c of contending vehicles is difficult because the time that holds a pending beacon is also a function of N_c, and it is not proportional to the number of neighboring vehicles as we will see in the following.

Given that each vehicle generates its beacon at the same mean rate B, we estimate N_c by considering the contending time or the active time $g(N_c)$ of a contending vehicle. An active time is defined as a time interval from when a vehicle has a packet to when the packet is successfully transmitted. We consider an average vehicle and its behavior under the assumption that all the vehicles behave statistically the same, e.g., all the vehicles have the same active time $g(N_c)$.

Suppose that the start of the active time of neighboring vehicles is uniformly distributed over a beacon period $\frac{1}{B}$. We pay attention to a vehicle that just has a packet. It will observe average $\frac{N_c}{2}$ beacon broadcasts from other contending vehicles before it makes a beacon transmission, because the half of N_c will finish the beacon transmission earlier than the vehicle of interest. Thus, during the active time, it will freeze its backoff timer for $\frac{N_c L}{2}$. Also, the waiting time, during which the backoff counter ticks, will be on average $\frac{W\sigma}{2}$ time. Thus, it takes $\frac{N_c L}{2}+\frac{W\sigma}{2}$ for the vehicle to transmit a beacon, followed by channel occupation for L time. Hence we obtain

$$g(N_c)=\frac{N_c L}{2}+\frac{W\sigma}{2}+L. \tag{9}$$

By definition, average number of vehicles whose active time partially overlaps with the vehicle of our interest is N_c. Suppose there are N_n vehicles in the road within a transmission range. Fig. 3 shows distributions of each vehicle's active time. Let t_1 and t_2 denote the start and the end of active time

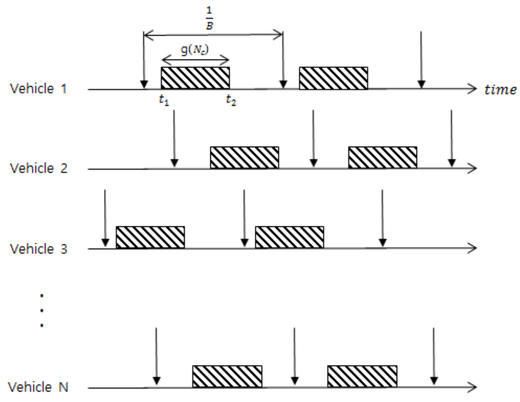

Fig. 3. Distributions of active time.

of the vehicle of our interest (vehicle 1). Since all the vehicles have the same length of active times and there are N_c contending vehicles whose active time partially overlaps with that of the vehicle, we will observe, at time t_1, $\frac{N_c}{2}$ contending vehicles. There are also additional $\frac{N_c}{2}$ contending vehicles that will start their active time during $[t_1, t_2]$. Let us focus on the start time of active times. We will have the start times uniformly distributed over a beacon interval $\frac{1}{B}$, and also observe $\frac{N_c}{2}$ start times during an active time $g(N_c)$. Since the ratio of the active time to the beacon period equals to the ratio of the expected number of contending vehicles to the expected number of vehicles within the transmission range, we have $\frac{g(N_c)}{1/B}=\frac{N_c/2}{N_n}$. Combining it with (9), we can obtain that

$$N_c=\frac{(BW\sigma+2BL)N_n}{1-BLN_n}.$$

Given the expected number of contending vehicles, we can calculate the probability of successful transmission of a beacon at a time. Let P_S denote the probability of successful transmission of a beacon. A vehicle can successfully transmit a beacon at a time when no one has same contention window size with its own among contending vehicles in its communication range. Thus, P_S is expressed as $P_S=\left(1-\frac{1}{W}\right)^{N_c}$. Note that if two vehicles encounter with each other, they can exchange the beacons within the transmission range. Let T denote the time, for which two vehicles are within the transmission range (i.e., encounter duration), then the probability P_S^T that a packet can be successfully delivered during the encounter can be obtained as

$$P_S^T=1-\left(1-P_S\right)^{\frac{T}{1/B}}. \tag{10}$$

4.3 Prediction-based forwarding

We now develop the forwarding decision scheme with the estimated successful transmission probability, denoted by Packet Delivery Prediction-based Data forwarding (PDPD). When there are a number of contending vehicles within a transmission range, a transmission attempt of the beacon will be likely to fail due to collision with other vehicles. Hence, it would be better to avoid the public vehicle that passes through a highly congested road.

Given a vehicle network with the public vehicles that can provide the Internet connection, our goal is to make a decision of carry-on or transmit for relay to satisfy reliable packet delivery from a packet source (private vehicle) to a packet destination (public vehicle). In this network, each vehicle has the following information: the smallest expected time T_e^a for vehicle V_a to encounter a public vehicle, the probability P_e^a of encounter the public vehicle, and the successful transmission probability $P_S^{T,a}$ during the encounter. The detailed algorithm is shown in Algorithm 1.

When a private vehicle $V_a \in V$ has a data packet to forward, it collects information from neighboring vehicles within its communication range, and among the neighboring vehicles $V_b \in V$ (including itself $V_a \in V$) such that $P_e^b \times P_S^{T,b} \geq p$ for some threshold

Algorithm 1: PDPD algorithm

```
If V_a ∈ V has a packet to send
 Set T_min = T_e^a
 For V_b ∈ V
 If V_b is in the communication range of V_a
  If P_e^b × P_S^{T,b} ≥ p for some threshold p
  If T_e^b < T_min
    T_min = T_e^b
   Next forwarder is V_b
  Else
   Next forwarder is V_a (carry-on)
```

p, it forward the packet to the vehicle $V_b \in V$ with minimum T_e^b as the next-hop. If there is no candidate vehicle in its neighborhood, it carries the packet until it meets another vehicle.

Ⅴ. Performance Evaluation

This section evaluates the performance of PDPD through simulations. The evaluation is based on the following wireless communication setting:

1) Wireless communication setting: In the network, each vehicle periodically broadcast a beacon at rate 10 (times/second). The distributed coordinated function (DCF) of IEEE 802.11 is used for medium access. Each vehicle has backoff timer, and randomly chooses an integer with range [0, 7] and decreases the integer value for every 13us slot time of idle channel. For simplicity, we do not consider exponential backoff in the case of multiple collisions. We assume that packet length is very small and two vehicles can quickly exchange (i.e., a packet takes 4ms to be transmitted). The communication range is 200m.

During the simulation, unless otherwise specified, we use the default values in Table 1.

We first verify the estimation of probability of successful transmission. Each vehicle generates its beacon over a beacon period, and when generating a beacon, it tries to transmit the beacon under the medium access control (e.g., CSMA/CA). We set the time that two vehicles can exchange the beacons

Table 1. Default parameters

Parameter	Description
Vehicle beacon interval	$1/B=0.1\text{sec}$
Contention window size	$W=7$
Contention slot time	$\sigma=13us$
Time for a beacon transmission	$L=4ms$
Communication range	$R=200m$

to 6 seconds, since two vehicles that travel in the opposite direction (each at 60km/h) can communicate with each other for approximately 6 seconds when the communication rage R is 200m. During this 6 seconds, we observe the attempt to transmit the beacon, the occurrence of collision and successful transmission for a vehicle, and measure the delivery ratio (i.e., the ratio of the number of successful transmission to the number of attempt). The simulation is repeated with increased number of neighboring vehicles. Fig. 4 shows the successful transmission probability as a function of the number of neighboring vehicles and compares the packet delivery ratio under different beacon length. As shown in the Fig. 4, our probability of successful packet transmission is well estimated.

We now verify whether the PDPD can provide a reliable and timely data forwarding when considering the probability of successful transmission on forwarding decision. To do this, we simulate with two different forwarding scheme: One only uses the encounter probability on forwarding decision, and the other uses both encounter probability and probability of successful transmission on forwarding decision. In each simulation, the threshold value is 0.5.

We consider a road network with 36 intersections, which forms a rectangular road network topology. We place 300 private vehicles on the top of the road network and 50 private vehicles on the bottom of the road network. We define the top of the road network as high vehicle density area and the bottom of the road network as low vehicle density area. Each private vehicle randomly chooses one of the intersections in each area as its start position, and randomly chooses another intersection as its destination position, and moved along the road.

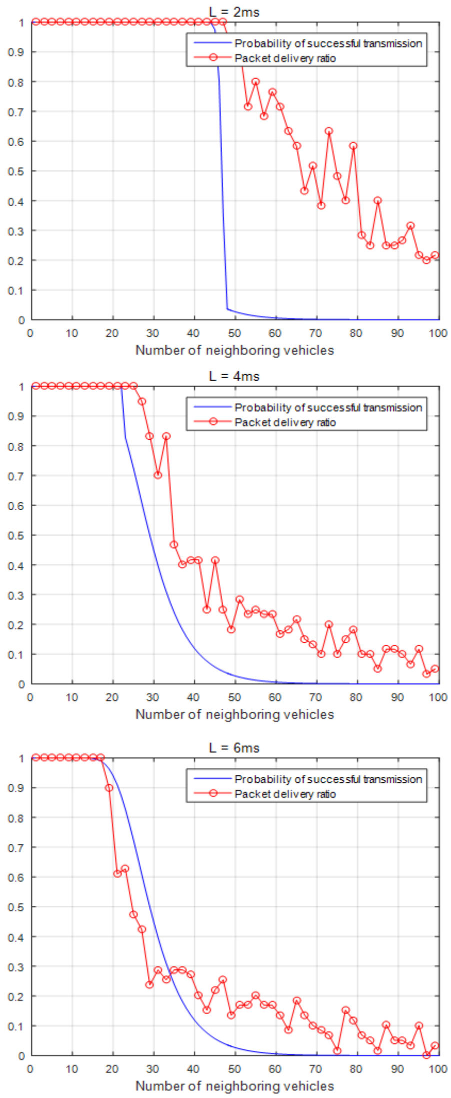

Fig. 4. The probability of successful transmission and delivery ratio comparison for different beacon transmission time ($L=2ms, 4ms, 6ms$).

Once it arrives at the destination position, the private vehicle repeats the random selection of next destination and moving. We also place 100 private vehicles in the perimeter of our road network, where they circulate to help the packet forwarding. Two public vehicle pass through one road segment in the top of the road network, and another two public vehicle pass through one road segment in the bottom of the road network.

We conduct 100 rounds of each simulation with different random seeds. Fig. 5 shows the impact of

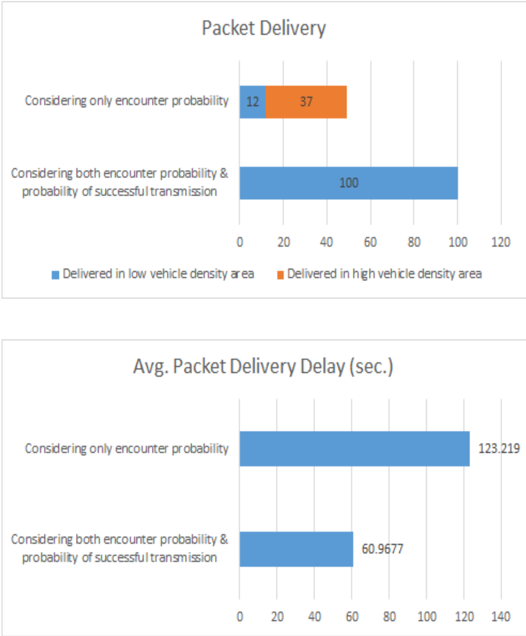

Fig. 5. The impact of the probability of successful transmission on packet delivery ratio and packet delivery delay.

the probability of successful transmission on packet delivery ratio and packet delivery delay. As we consider probability of successful transmission on forwarding decision, a packet is delivered in low vehicle density area rather than high vehicle density area, so the packet delivery ratio is improved. We also find that the average delivery delay of the packet is lower than the case of considering only the encounter probability on forwarding decision. The reason is that, since there are few chances to grab the channel in high vehicle density area, the packet is often carried by the vehicle rather than forwarding through wireless communications. It results in slow propagation of the packet.

Now we compare performance of our PDPD with GPCR in terms of packet delivery ratio and average packet delivery delay. In our simulation, we use a road network with 25 intersections. We change the number of vehicles. Each vehicle has a random starting point at one of the intersections, and sets its ending point of another intersection at random. For routing between the starting point to the ending point, we apply the standard Dijkstra's algorithm.

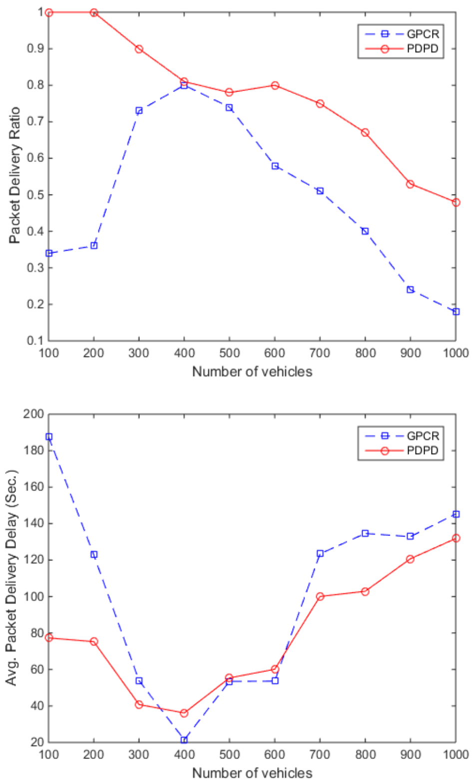

Fig. 6. Performance comparison with GPCR.

The movement of the vehicle is then constrained along the shortest route. When a vehicle arrives at its ending point, it repeats the movement procedure by setting another ending point at random.

The speed of each vehicle follows the normal distribution of $N(\mu_v, \sigma_v)$ where $\mu_v = 60km/h$ and $\sigma_v = 20km/h$[23]. We set the vehicle speed at the entrance of a road segment so that a vehicle may have a different speed at each road segment. Two public vehicles are used as packet destination. Each public vehicle moves around in the perimeter of center of the road network, which is fixed. During the simulation, 100 packets are dynamically generated from a specific private vehicle in the road network, which circulate in the perimeter of whole road network. We continue each simulation run until all of these packets are delivered or dropped (when current packet carrier arrives at its destination, then the packet is dropped).

We investigate the performance of PDPD with different vehicular densities. We vary the vehicle number from 100 to 1000 (the vehicular density can be expressed by the number of vehicles in the network). As shown in Fig. 6, with different densities, PDPD always outperforms GPCR in terms of packet delivery ratio. This is because (1) the trajectory information provides more accurate knowledge for forwarding decision and (2) with the probability of successful transmission, PDPD can avoid delivering a packet to a public vehicle which passes through high density area where the transmission will be likely to fail due to collision with other vehicles.

GPCR shows the best performance when the number of vehicles is 400. As the number of vehicles increases (from 100), it is more likely to meet a vehicle toward the destination, which decreases the packet delivery delay. On the other hand, as the number of vehicles increases high (> 500), the packet is likely to be forwarded to a crowded area, where wireless transmission often fails. This decreases the packet delivery ratio, and also contributes to long delay since vehicles are more likely to deliver the packet by carry-on. PDPD also suffers from poor wireless channels, but show much better performance than GPCR by avoiding crowded areas if possible.

Ⅵ. Conclusion

VANET, one of core technology of ITS for a variety of services, is the essential element to the realization of traffic environments with better safety and efficiency. Routing protocols in VANET have been developed for decades and often designed based on routing protocols in MANET. However, the requirement of high mobility support in VANETs makes it more challenging despite recent advance in communication technology. In this paper, we propose a reliable vehicle-to-vehicle data delivery called Packet Delivery Prediction-based Data Forwarding (PDPD), accounting for traffic statistics and quality of wireless communications. PDPD uses two probabilities to guide forwarding decision; the encounter probability of two vehicles that is the next forwarder and the destination vehicles, and the probability of successful transmission at the encounter place. We evaluate our proposed schemes through simulations. The results show that packets can be delivered in a more reliable manner under the proposed scheme by considering the probability of successful transmission in vehicular networks.

References

[1] S. Heo and S. Yoo, "Multi-Channel MAC protocol based on V2I/V2V collaboration in VANET," *J. KICS*, vol. 40, no. 1, pp. 96-107, Jan. 2015.

[2] J. Bernsen and D. Manivannan, "Unicast routing protocols for vehicular ad hoc networks: A critical comparison and classification," *Pervasive and Mob. Comput.*, vol. 5, no. 1, pp. 1-18, Dec. 2009.

[3] S. Cho and S. Kim, "Routing algorithm of VANET for an efficient path management in Urban Intersections," *J. KICS*, vol. 38A, no. 12, Dec. 2013.

[4] H. Ahn, J. Yim, Y. Ko, H. Choi, and D. Kwon, "Ad hoc routing method based on betweenness centrality and location information for unmanned ground system networks," *J. KICS*, vol. 41, no. 4, Apr. 2016.

[5] S. Taneja and K. Ashwani, "A Survey of routing protocols in mobile ad hoc networks," *Int. J. Innovation, Management and Technol.*, vol. 1, no. 3, pp. 279-285, Aug. 2010.

[6] S. Jaap, B. Marc, and Lars Wolf, "Evaluation of routing protocols for vehicular ad hoc networks in typical road traffic scenarios," in *Proc. 11th EUNICE Open Eur. Summer School on Networked Appl.*, Jul. 2005.

[7] V. Naumov and T. Gross, "Scalability of routing methods in ad hoc networks," *Performance Evaluation*, vol. 62, no. 1, pp. 193-209, Oct. 2005.

[8] B. Kar and H.-T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," in *Proc. 6th Annu. Int. Conf. Mob.*

Comput. and Netw., Oct. 2000.

[9] D. B. Johnson and D. A. Maltz, “Dynamic source routing in ad hoc wireless networks,” *Mob. Comput.*, vol. 353, pp. 153-181, 1996.

[10] C. Lochert, et al., “Geographic routing in city scenarios,” *ACM Mob. Comput. and Commun. Rev.*, vol. 9, no. 1, Jan. 2005.

[11] C. Lochert, et al., “A routing strategy for vehicular ad hoc networks in city environments,” *IEEE Intell. Veh. Symp.*, Jun. 2003.

[12] J. Zhao and G. Cao, “VADD: Vehicle-assisted data delivery in vehicular ad hoc networks,” *IEEE Trans. Veh. Technol.*, vol. 57, no. 3, May 2008.

[13] Y. Ding, C. Wang, and Li Xiao. “A static-node assisted adaptive routing protocol in vehicular networks,” *ACM Int. Wksp. Veh. Ad Hoc Netw.*, Sept. 2007.

[14] J. Jeong, et al., “Trajectory-based data forwarding for light-traffic vehicular ad hoc networks,” *IEEE Trans. Parall. and Distrib. Syst.*, vol. 22, no. 5, May 2011.

[15] J. Jeong, et al., “Trajectory-based statistical forwarding for multihop infrastructure-to-vehicle data delivery,” *IEEE Trans. Mob. Comput.*, vol. 11, no. 10, Aug. 2012.

[16] GyeongGi-Do Transportation Information Center, Retrieved Jan. 31, 2016, from http://gits.gg.go.kr

[17] R. A. Uzcategui, A. J. De Sucre, and G. Acosta-Marum, “Wave: A tutorial,” *IEEE Commun. Mag.*, vol. 47, no. 5, May 2009.

[18] J. Jeong, et al., “TPD: Travel prediction-based data forwarding for light-traffic vehicular networks,” *Comput. Netw.*, vol. 93, no. 1, Dec. 2015.

[19] A. Polus, “A study of travel time and reliability on arterial routes,” *Transportation*, vol. 8, no. 2, pp. 141-151, Jun. 1979.

[20] M. H. DeGrrot and M. J. Schervish, *Probability and statistics*, 4th Ed., Pearson Education, 2002.

[21] Garmin Ltd., Garmin traffic. http://www8.garmin.com/traffic/.

[22] IEEE 802.11 Working Group, IEEE Standard for Information Technology – *Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 6: Wireless Access in Vehicular Environments*, IEEE Std 802.11p, Jul. 2010.

[23] D. S. Berry and D. M. Belmont, “Distribution of vehicle speeds and travel times,” in *Proc. 2nd Berkeley Symp. Math. Statist. Probability*, 1951.

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