Practical Location-based Routing in Vehicular Ad Hoc Networks

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Abstract—**Rapid advancement in wireless communication has made it possible to develop vehicular ad hoc networks, in which a vehicle can communicate with other vehicles via a wireless, multi-hope fashion. A variety of appealing real-world applications can be enabled by VANETs, such as driving safety and urban monitoring. Many location based routing algorithms have been proposed for data delivery in VANETs. Most of them assume that accurate location information is available when needed. In practice, however, such assumption is unrealistic. It incurs considerable cost to retrieve location information. In addition, a vehicle is on the fast move over time, and a location previously obtained may become invalid after certain time. This paper proposes a routing algorithm that is based on a practical location information model. To solve the problem of location inaccuracy and vehicle mobility, we devise a location predictor which estimates the possible location of a vehicle by using history information. Based on the greedy forwarding strategy, the proposed routing differentiates packets in terms of closeness to destination and jump distance. We evaluate the performance of the proposed algorithms with a large real trace of taxi motion in Shanghai. Trace-driven simulation results demonstrate that data delivery performance is improved.**

Keywords-Routing Protocol, Vehicular Ad Hoc Networks

I. INTRODUCTION

Vehicles are more and more becoming a necessity in our daily life, and spread the city everywhere. Today we have witnessed the rapid development of wireless communication, from cellular systems to WiFi. The combination of vehicles and wireless communication has created a promising area of vehicular ad hot networks (VANETs) [13]. Being equipped with a wireless transceiver, a vehicle can communicate with other vehicles when they move close to within the communication range, which depends on the specific wireless technology. A wide range of appealing applications can be developed with VANETs, from driving safety [12] to urban monitoring [8]. In driving safety, for example, when a vehicle observes a traffic incident, it can broadcast an emergency alarm to other vehicles which can then take measures to drive around the incident.

VANETs exhibit unique features. First, vehicles have high mobility and the topology of a VANET can be changing quickly over time. The connection between vehicles is frequently disrupted. Second, being spread over a vast area, the vehicles may not be able to form a connected network. That means at a given time instance, there does not exist a connected path for an end node to reach another end node. Third, the vehicles are distributed with different densities. It is a typical setting that vehicles are densely populated in some hot regions, whereas there are just a few vehicles in some other regions. These characteristics together suggest that most existing designs and solutions for traditional network systems, such as MANETs and the Internet cannot be straightly applied.

Routing is an essential building block for VANETs, which determines how the data can be delivered from a vehicle to another vehicle in the network. Many location-based routing algorithms have been proposed, which share the core idea that a packet destined to a remote vehicle is always forwarded towards the direction of the destination. By following such a routing strategy, the packet can eventually reach the destination node. Most of existing location-based routing algorithms, however, take it for granted that the location information of the destination vehicle is accessed in real time. Nevertheless, such assumption is impractical in the real world.

A vehicle must maintains its location information over time, and make it available by some means, for example, publishing it to a location server that is accessible to the public. For a vehicle to get the location information of another vehicle, it has to establish a connection with the provider of location information. Note that both reporting location information to the location server and retrieving location information from the provider requires remote connection that typically introduces considerable cost. Today, the cellular system is most widely available service with coverage of large scale and pervasive connection on the move. For example, however, data communication on the GPRS system is a practical way, by which a volume of 1Mbytes costs about $1 with ChinaMobile [1]. Although frequent updates and retrieval can result in more accurate location information, a higher cost must be paid. Therefore, it is impractical to assume that location information can be retrieved in real time and the obtained location information is accurate.

The location information is crucial in making the decision of forwarding a packet. If the location information is time lagged and deviates from the real location of a vehicle, the forwarding decision may lead to poor performance of data delivery. To solve this problem, this paper proposes a practical routing for VANETs, which takes into account location inaccuracy and time lag. In essence, the algorithm incorporates a location predator that estimate the possible location based on the speed and history information. Then, a better forwarding decision can be made when compared to the one ignoring location inaccuracy. Furth more, the duration of a contact is short, and

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Figure 1. The sensing device equipped on a Taxi, together with displayed information

recent empirical study in Boston has shown that the typical duration of a contact between a driving vehicle and a road side AP is as short as 10s [3]. This implies that during a contact just a few packets can be delivered. Thus, the selection of which packets to be sent in a contact is important. Our routing algorithms differentiate packets according to different metrics in order to achieve better delivery performance.

The rest of this paper is organized as follows. Section II discusses related work and highlights the differences of our routing algorithms from existing ones. Section III introduces the system background, including a prototype of VANET in Shanghai, and the practical location service implemented in this prototype. Section IV details the design of our routing protocol. The evaluation based on trace-driven simulations and performance analysis are described Section V. This paper concludes in Section VI.

II. Related Work

A lot of research efforts have been made to develop routing protocols that are suitable for VANETs. In general, the existing algorithms can be classified into three classes.

A. Broadcast

These protocols deliver data by broadcasting many copies. Epidemic routing [11] is a typical one among these protocols. It is firstly proposed for delay tolerant networks (DTN) [4]. Lately, researchers borrow it and use it in VANETs since VANETs share with DTN in frequent disruption. When two nodes contact, they exchange the metadata of packets they carried and then transfer to each other the packets that the other side does not have. This process is analogous to disease infection. It is assumed that a node has unlimited buffers and bandwidth. This scheme is efficient when little information is on the hand. However, when the buffer size and bandwidth become limited, its performance drops quickly. A lot of variations try to solve the problem of flood storm by controlling TTL and forward times.

B. Opportunistic routing

Opportunistic routing focuses on opportunities that two nodes contact each other. It is believed that the movement of vehicles follows certain laws. MaxProp [2] tries to figure out the probability that two node contact from historic information, and then determine the most likely delivery path to forward packets. In [9], a routing algorithm based on MobySpace is proposed. In this space, mobility patterns of nodes are described by a vector $V_i = (p_1, p_2, \ldots, p_n)$, p_j denotes the probability that node i appears in location j. Two nodes often appear in the same location would likely to meet again, when they could exchange data. Thus, forwarding packets to the nearest node to the destination in the MobySpace is likely to be successful.

C. Location-based routing

In contrast to conventional topology-based routing, location based routing protocols use position information that can be obtained via location sensing device (e.g., GPS). In [5], the authors introduce a location service to locate the destination node, and implement a routing protocol that is similar to GPSR [7]. It is assumed that the location service can provide accurate location information, which is impractical in the real world.

In [10], a method is proposed to generate a routing path on the digital map that has the shortest length. In [6], the authors propose a greedy routing protocol, which take into account the length and traffic condition of a particular road.

III. System Backgound

In this section, we introduce the system background with which this routing protocol is developed. A prototype of VANET has been developed at Shanghai Jiao Tong University. In this prototype, more than 4000 taxies are employed, which run in the urban area of Shanghai, covering an area of up to $110km^2$. In Figure 3, a snapshot of the topology formed by the taxies is illustrated.

Location information is essential for VANETs and many real life applications built on VANETs. As a first step, each vehicle is equipped with a sensing device, as shown in Figure 1. The sensing device provides position, velocity, and taxi occupancy. Position and velocity information is measured by a GPS receiver. Thus, the position is in the format of a tuple of longitude and latitude.

Many interesting applications have been investigated, for example, traffic monitoring [14] and file sharing. For a file sharing application, a routing protocol is necessary, with which a vehicle needs to send data to another vehicle. In this paper, we consider there are n vehicles $V=\{1,2,3, \ldots, n\}$. Each vehicle is assigned a unique ID. We consider unique, that is, each vehicle i may want to send data to another vehicle j, $(i,j \in V)$.

A. Practical location service

There are many ways for providing location information for a VANET, by which one is able to query about the current location of a vehicle. In the prototype, we have implemented a practical location service which introduces only a reasonable cost, as shown in Figure 2.

We describe the location service in the following. Each vehicle has a GPRS channel available with the cellular system. Each vehicle reports, though the GPRS channel, its location and speed information every T seconds (T∈[60, 180]). There is

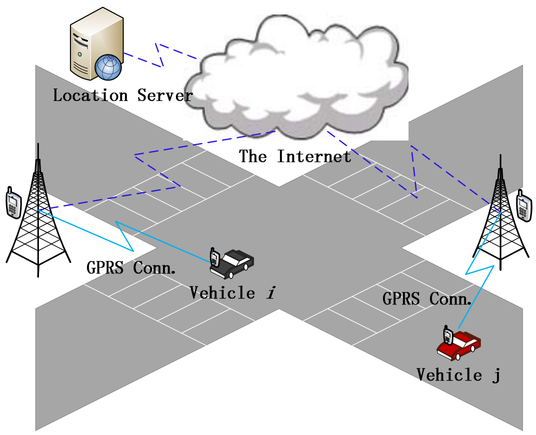

Figure 2. The architecture of location service in the prototype

a location service which hosts all location information of the vehicles, which is connected to the Internet. For a vehicle *j*, it can retrieve the current location of vehicle *i*, by querying the location server. Such query can be initiated any time on demand. Note that before such the queried location information reach vehicle *j*, it must experience a certain delay introduced by the cellular system and the Internet.

IV. PROTOCOL DESIGN

The location based routing protocol consists of three components, including location predictor, greedy forwarding and buffer management.

A. *Location prediction*

We device a location predictor that estimates the current location of a vehicle based on its history location and velocity. It is unavoidable that there is a time gap between the time instance of retrieval and that of location update. Suppose node *i*

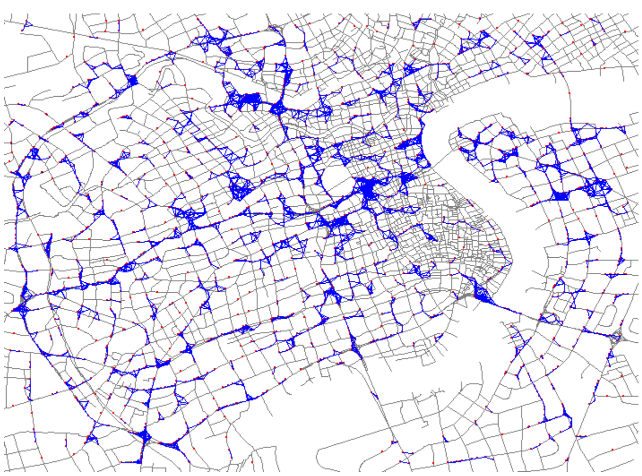

Figure 3. A snapshot of the topology formed by the vehicles in the prototype, embedded in the road map of Shanghai.

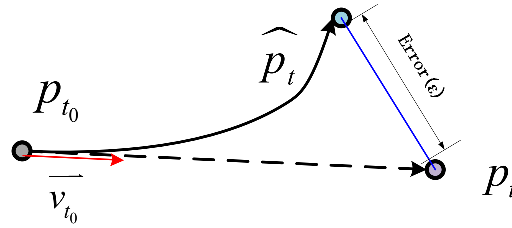

Figure 4. Illustration for location prediction.

reported its position p_{t_0} and instant velocity $\overline{v_{t_0}}$ to database at time t_0. At time t, node j requests the position of node i. Let Δt denote the time gap, $\Delta t = t - t_0$. Then, the predictor assumes that node *i* does not change its velocity (both direction and magnitude). Thus, as illustrated in Figure 4, the estimated position of the current location of *i* is

$$\widehat{p_t} = p_{t_0} + \overline{v_{t_0}} \times \Delta t \ .$$

There is an error ε between the real location and the estimated location,

$$\varepsilon = p_t - \widehat{p_t} \ .$$

In Figure 6, the error distribution is shown when speed and location update delay are varied.

Since upon making a prediction a relay node does not know the real location of the destination node, it is impossible for it to evaluate the error of the prediction. By applying the location predictor using a large trace of taxi motion trace, we find that the average prediction error can be approximated as

$$\varepsilon = \frac{1}{2} \times \overline{v_{t_0}} \times \Delta t$$

To quantify the quality of a prediction, we define the reliability (r) as follows,

$$r = 1 - \frac{\varepsilon}{p_t - p_{t_0}} \ .$$

This definition implies that when the prediction node is far from the node to be predicted, the prediction error introduces a slighter influence, and vice versa.

B. *Greedy forwarding*

The greedy forwarding strategy has two subcomponents: neighbor selection and packet selection.

Once a new packet is injected into the VANET, the source node requests the location server to obtain the current location information of the destination node, including its physical coordinate, speed, and the timestamp of this information. The source node appends this information to the packet header. Note that vehicles update their location information to the location server in a fixed period. Relay nodes keeps update this information if the location information of the destination node is updated at the location server.

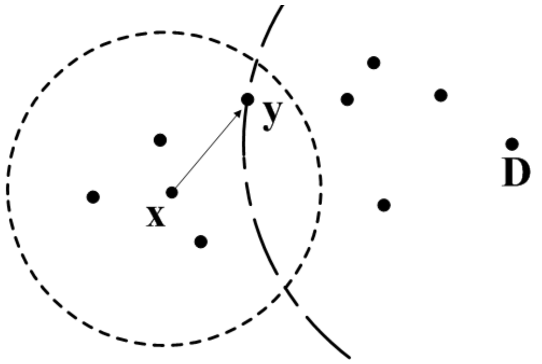

Figure 5. Next hop selection. Node *x* wants to forward a packet to node *D*. The packet is forwarded to node *y* that is the nearest to *D* in the set of *x*'s neighbors.

As a result, when making the forwarding decision, a relay node makes a decision based on the location information of the destination node embedded in the packet header.

For next hop selection, our greedy forwarding algorithm employs the strategy proposed in [7]. According this strategy, a packet is forwarded to the neighbor that is closest to the destination node, as shown in Figure 5. When such a neighbor does not exist, a resolution is applied as described in [7].

Another key issue is which packet among all in the buffer should be forwarded first. Due to the limited bandwidth and short contact duration, only a limited number of packets can be transferred during a contact. That means the relay node cannot forward all packets in this contact. Thus, the selection of packets to forward is of great importance.

There are two strategies to sort the packets for forwarding:

Nearest first strategy (NFS). The packet that is closest to its destination takes the highest priority to be forwarded. To sort the packets, each packet is assigned a score,

$$G(p_k) = r(p_k) / d(p_k),$$

where p_k is the candidate packet, $r(p_k)$ is the reliability of the predicted location of the packet's destination, and $d(p_k)$ is the residual distance of the packet (i.e., the distance between the relay node to the destination). On deciding which packets to forward, a relay node forwards packets in the decreasing order according to the priority score.

Maximum jump strategy (MJS). The packet that makes the maximum jump is forwarded first. That is, this packet takes the highest priority. The maximum jump is the maximum reduction on the distance to the destination, for the packet, if this packet is forwarded to the next hop. To compute the priority score of each packet, we use the reliability as weight,

$$G(p_k) = r(p_k) \times f(p_k)$$

where $f(p_k)$ is the maximum forwarding step. The packets are selected to forward in the decreasing order of $G(p_k)$.

C. *Buffer management*

A vehicle has a limited storage, and hence we have to consider buffer management. When the buffer of a vehicle is full, we need a strategy to discard some existing packets in order to make space to accommodate new packets. We implement three buffer replacement strategies:

- **Residual distance strategy (RDS)**: the packet with the maximum residual distance to the destination node is replaced first.
- **Elapsed time strategy (ETS)**: the packet with the maximum time elapsed from departure from the source node is replaced first.
- **Rejection strategy (RJS)**: no replacement is made. Upon reception of a new packet, the relay node responds to the sender with an indication of full buffer. The sender then selects another neighbor as the next hop.

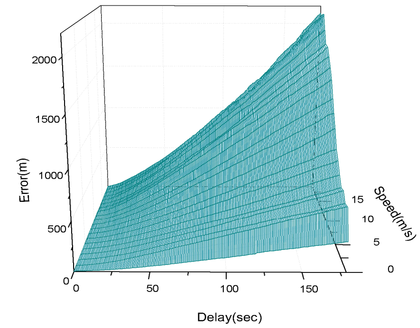

Figure 6. Error distribution as a function of delay and speed in the prediction.

V. Performance Evaluation

To evaluate the performance of the proposed routing protocol, we conduct extensive trace-driven simulation. We have collected a large trace of taxi motion of more than 4000 taxies that are operational in the urban area of Shanghai. The trace is collected in November 2006, which spans 15 days.

A. *Simulation setup*

We adopt the parameters for a vehicle as shown in Table 1. The source-destinations pairs are randomly selected. In the first 300 seconds of each simulation run, we generate network traffic. Two types of traffic condition are studied. In a light workload scenario, 6000 pairs are selected, and each source node generates one packet for its destination. In the heavy workload scenario, 12000 pairs are selected. For each simulation setting, we compute the average of 3 runs.

Table 1: Parameters

Communication Range	200m
Packet Size	256KB
Buffer Size	8MB
Bandwidth	2Mbps

B. *Performance metrics*

In performance evaluation, we focus on the following three metrics.

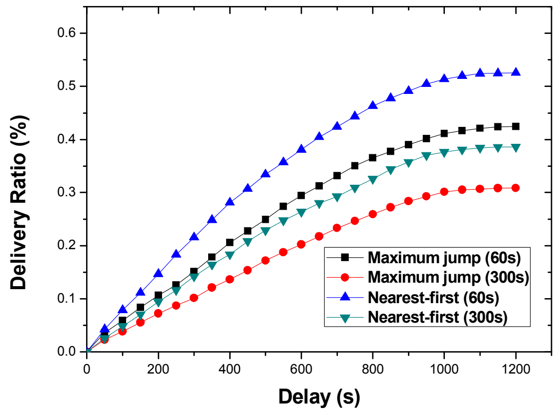

Figure 9. Fraction of delivery as function of delay for two routing algorithms, nearest first and max jump, with different two update periods.

- *Delivery ratio*: the ratio of successfully delivered packets to the total packets to transfer. A higher delivery ration is always desired for the design of a routing protocol in a VANET.
- *Average delay*: the average delay of all the packets that are successfully delivered. From the application point of view, it is apparent that a shorter delivery delay is preferable.
- *Transmissions*: the total number of packet transmissions in the whole network. This metric reflects the resource consumption during the execution of the routing protocol in the network.

C. *Simulation results*

1) *Impact of update frequency*

We study the performance of two greedy forwarding strategies with location prediction under different location update frequency. In Figure 9, we find that as the update period becomes longer, the delivery ratio decreases. It is intuitive that the prediction error increases when the update period is longer. A larger prediction error results in poor delivery performance. In addition, we find that the nearest first strategy outperforms the maximum jump strategy.

TABLE 2: COMPARISON OF DATA DELIVERY W/O PREDICTION

Settings	Delivery ratio (%)	Average delay (s)	Transmissions $(\times 10^4)$
NFS(w)	45.82	443.0	33.5
NFS(w/o)	48.70	433.5	31.5
MJS(w)	36.90	468.5	28.3
MJS(w/o)	38.07	446.8	26.4

2) *Effect of location prediction*

We study the effectiveness of location prediction by comparing delivery performance without and with location prediction. From Figure 7 and Figure 8, we can see with location pre-

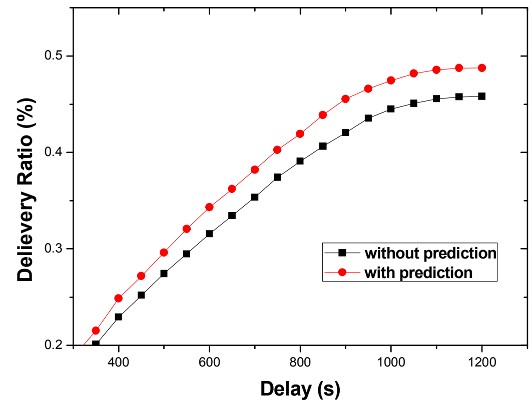

Figure 7. Fraction of delivery as function of delay for nearest first forwarding with/without prediction.

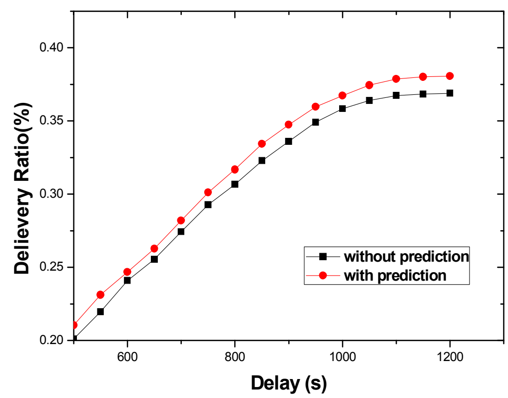

Figure 8. Fraction of delivery as function of delay for maximum jump forwarding with/without prediction.

diction the performance of data delivery is improved for both routing strategies. In Table 2, more detailed comparisons are made. The delivery ratio of both routing strategies with location prediction is slightly increased, and the average delay is decreased.

3) *Effect of reliability weight*

Applying the reliability weight filters poor location prediction in making a forwarding decision. We study the effect of applying such a reliability weight. We compare delivery performance of two routing strategies with and without applying reliability weight. Table 3 shows the comparison of the effects.

TABLE 3: COMPARISON OF DATA DELIVERY W/O APPLYING RELIABILITY WEIGHT

Settings	Delivery ratio (%)	Average delay (s)	Transmissions $(\times 10^4)$
NFS(w/o)	48.70	433.5	31.5
MJS(w/o)	38.07	446.8	26.4
NFS(w)	48.90	428.0	30.2
MJS(w)	49.10	460.1	30.1

We can see that when using the MJS forwarding strategy, applying the reliability weight contributes an increase of about 10% in delivery ratio. Meanwhile, however, it makes the delivery delay a litter longer. The number of transmissions remains almost the same.

4) Effect of buffer management

We study the effect of buffer management under different management strategies. In this simulation, the routing protocol is the combination of MJS with location prediction, but being weighted by reliability. Table 4 and Table 5 show the results under light traffic and heavy traffic, respectively. We can see that the RJS strategy has highest delivery ratio, but also introduces longer delay and more transmissions. RDS and ETS have similar performance.

TABLE 4: COMPARISON OF BUFFER MANAGEMENT UNDER LIGHT WORKLOAD

Strategy	Delivery ratio (%)	Average delay (s)	Transmissions ($\times 10^4$)
RDS	49.10	460.1	30.1
ETS	49.30	453.6	30.0
RJS	51.83	474.4	31.4

TABLE 5: COMPARISON OF BUFFER MANAGEMENT UNDER HEAVY WORKLOAD

Strategy	Delivery ratio (%)	Average delay (s)	Transmissions ($\times 10^4$)
RDS	34.92	444.2	46.7
ETS	35.04	446.5	46.7
RJS	40.75	473.4	53.9

VI. CONCLUSION

This paper has presented a practical location based routing protocol for VANETs. The design of such a routing is in response to the unrealistic assumption widely made by previous routing protocols that the accurate location of the destination node can be obtained in real time. Such idealized assumption makes existing routing protocols inappropriate in the real world. The proposed practical routing makes use of a simple location predictor that estimates the location of the destination node by using its speed and location information previously acquired. In addition, the routing design also considers the practical constraints posed by short contact duration of vehicles on the move. Trace-driven simulation results show that the practical location-based routing protocol improves data delivery performance in VANETs compared with other alternative protocols.

This work is still preliminary, and acts as the first step to studying routing design under a practical location service. Future research will proceed mainly in how to improve the quality of location prediction. In this work a simple prediction method has been applied. Better prediction will be explored. For example, the history track of a vehicle, and the restriction of the underlying road network will be taken into account. We believe that the routing performance can be further improved when the location predictor produces better location estimation.

VII. ACKNOWLEDGMENTS

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