An Opportunistic Dissemination Model for Traffic Congestion Management in Vehicular Networks

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***Abstract*—Road congestion has troubled hundreds of thousands of drivers for a long time. In recent years, an application named Dynamic Routing, in which vehicles reroute themselves around congested areas with road information received, is proposed to deal with traffic jam. However, due to the high mobility of the topology of vehicular networks, conventional Ad-Hoc routing is not suitable in Dynamic Routing. As a result, the opportunistic routing might play an important role in this field due to its disruption-tolerant nature. In this paper, we propose a geo-based opportunistic information dissemination model tailored for Dynamic Routing. Instead of the assumption that vehicles participate in message exchanging unconditionally or stand alone completely, we think that a considerable proportion of vehicles in real life belong to certain groups and take the willingness to make contributions to their own groups' driving conditions as a rational cooperation incentive. We evaluate the performance of our model and its effect on saving trip-time in a realistic scenario on an integrated simulation platform. The experimental results show that our dissemination model decreases forwarding overhead dramatically while still delivering as many useful messages into right vehicles as conventional broadcast algorithm does. We also evaluate the performance of different groups in terms of forwarding efficiency and trip-time improvement.**

Keywords—Dynamic Routing; geo-based; opportunistic network; TraCI.

I. INTRODUCTION

Traffic congestion has long been a hot topic in the study of Intelligent Transport System (ITS). One solution to this problem is Dynamic Routing, in which vehicles equipped with Short-Range Devices (SRD) may re-compute their path with local digital maps and congestion warning (CW) messages received to route around congested streets.

The dissemination of CW messages based on infrastructure seems to be a feasible solution, but the prohibitive expense makes it hard to be deployed globally. On the other hand, researches on opportunistic routing mechanism provide an alternative to exploit inter-vehicle communication to disseminate messages in an opportunistic manner.

Geo-based opportunistic routing is one of the main branches of opportunistic routing researches. In geo-based opportunistic routing, the holder of a message tries to find a neighbor node that is "closer" to the target under a certain distance definition. Since many vehicles are already equipped with GPS devices, position information is now readily available. This leads to a great potential for geo-based opportunistic routing.

Many researches have been done, aiming to establish a general information dissemination framework. However, each algorithm needs to be tailored for user applications before it is put into use, especially the metric they apply in next relay selection process. More specifically, in Dynamic Routing, the originator of a CW message knows neither IDs nor locations of potential receivers. Consequently, the distance to the target cannot be calculated. Dynamic Routing needs a geo-cast featured information dissemination model, and some researches reveal that candidates' vehicle information will be of great help in relay selection [6][7].

Rational selfishness has also been regarded as a vehicle's nature. Vehicles may not bother to originate and forward CW messages to enhance other vehicles' driving condition. However, vehicles of the same group, such as taxis of a single company, would like to help divert their partners away from congested roads. How this partial cooperation would affect message dissemination and vehicles' trip-time improvement also needs to be investigated further.

In this paper, we propose a new geo-based information dissemination model, named Direction-Assisted Geographic Relay (DAGR) for Dynamic Routing. The model takes relay candidate's moving direction and route into consideration while still leaving carry-CW-or-not decision for relay candidates to make. We evaluate the performance of our model on an integrated simulation platform proposed by A. Wegener *et al.* [12]. The results help us understand the impact of grouping of vehicles on dissemination and how trip-time improvements are distributed in a real city scenario.

The remainder of this paper is organized as follows. We start by describing the existing related works in Section II, and then illustrate DAGR's mechanism in Section III. In Section IV, we present our simulation setup and discuss some experimental results. Finally, Section V concludes the paper.

II. RELATED WORK

Vehicular network is conventionally modeled as a planar graph where nodes are junctions and links are road segments. A vehicle may have a chance to forward a message as it approaches a junction [1][2].

In Geographic Delay-Tolerant Network (GeoDTN) Routing, Cheng *et al.* [3] summarized and categorized geo-based routing algorithms in vehicular networks. The routing process is divided into greedy mode, perimeter mode and DTN mode. Vehicles are classified into 4 categories by the deterministic of their destinations and routes. Different distance metrics are defined for each category to guide the switch between routing modes and next relay selection.

Lee *et al.* studied vehicles' behavior at junctions in a micro perspective in [4]. Instead of choosing a farthest 1-hop neighbor as next relay, they proposed an augmented beacon to collect topology information within 2-hop area, and argued that this may help select a relay closer to the target in the situation that routes might be blocked by street topology. Ma *et al.* [5] used angle of vehicles' motion vectors as a metric in relay selection and suggested that the bus system can be a communication backbone in geo-based opportunistic delivery service because of its high punctuality and deterministic of its route and destination.

All these geo-based algorithms require that applications know targets' positions or IDs in advance. While in Dynamic Routing, the originator and forwarders of a message have no idea who may need it and where they are. To disseminate road information in the network quickly and widely, Wischhof *et al.* proposed a simple message dissemination algorithm in [6], which broadcasts messages road by road firstly. Then, through measuring some road condition parameters such as car density and average speed, forwarders may adjust the broadcast interval to decrease communication overhead.

Yang *et al.* evaluated the effectiveness of Dynamic Routing and the feasibility of broadcast interval adjustment through simulation in [7]. Meanwhile they also found that relay candidates' vehicle information can be very useful in selecting a good relay. Similar results also appeared in [8].

From another perspective, Leontiadis *et al.* argued that there is no need to broadcast all cached congestion warning messages in a junction. Applying gossip algorithm, the Computer-Assisted Traveling Environment (CATE) model they proposed defines a utility function and selectively broadcasts a sample of messages [9]. The simulation results show that it still achieves a notable trip-time improvement.

III. DIRECTION-ASSISTED GEOGRAPHIC RELAY MODEL

A. Assumptions and Proposed Model

The urban map is modeled as a weighted graph in Dynamic Routing. Each road segment is associated with a travel time as a weight. The default value is computed dividing the segment's length by the speed limit. Once a vehicle's time spent in a road segment surpasses a travel delay threshold, a CW message consisting of road ID and travel delay will be originated and broadcast. This message would be spread into the network, ether in an Ad Hoc or in an opportunistic mode. Upon receiving the message, receivers update their local weighted graphs and apply Shortest Path Algorithms (mostly Dijkstra) to re-compute new routes. Discussions in previous researches have revealed that in the process of selecting a relay, motion information of candidates, e.g., position, direction and route, may improve final trip-time dramatically. Since drivers might regard routes and directions as privacy, advertising this information might not be plausible.

We propose a new geo-based dissemination model for Dynamic Routing, named Direction-Assisted Geographic Relay (DAGR). In this model, the holder of a message just simply broadcasts it in certain conditions and every vehicle v_o that overhears the message decides whether to carry it or not. The decision-making process depends on v_o's direction and its relative position with the message originator v_a.

In our scenario, vehicles are categorized into 4 types.

1) *Non-equipped vehicle:* Vehicles that are NOT equipped with SRDs and do NO rerouting.

2) *Public vehicle:* Vehicles that ALWAYS originate and forward CW messages selflessly when necessary and do rerouting with them, e.g., police cars, buses.

3) *Private vehicle:* Vehicles that NEITHER originate nor forward CW messages. But they DO rerouting with messages overheard from others.

4) *Group vehicle:* Vehicles that originate and forward messages ONLY when there are vehicles of the same group in vicinity, e.g., cars of the same taxi company.

As to the adversary model, faking congestion warning to divert traffic to other areas is studied in [9], and it turned out that it required a significant size of misbehaving nodes (>22% of the total vehicles) to collaborate to make vehicles' trip-time deteriorate notably. So, in our model, the selfishness of vehicles is regarded as the passive attitude in message exchanging instead of broadcasting malicious messages. To inform 1-hop neighbors of their existences, Public and Group vehicles broadcast short HELLO beacons constantly, while Private vehicles always keep silent and just reroute with CW messages overheard from others. So, they are just free-riders.

B. Dissemination Performance Metric

The design goal of our dissemination model is to enhance the forward efficiency of CW messages. This means that vehicles in the scenario should only carry and forward messages most likely to make contribution to traffic-jam avoidance, instead of simply forwarding every message they overheard. In fact, most CW messages are of no use to a given vehicle if it contains no roads that consist of the vehicle's route. So, we need a new metric rather than simple delivery ratio when evaluating dissemination performance in Dynamic Routing. Before any further discussion, Table I lists some symbols we may encounter in the rest of this paper.

TABLE I. SYMBOL CONVENTIONS

v	vehicle, v_a denotes a vehicle with ID a.
G	group of vehicles, G_b is a group with ID b.
l	road segment, a one-way road between two adjacent junctions. l_k is a road segment with ID k.
R	route, a sequence consisting of continuous and non-repeating road segments.
p_v^t	v's GPS position at time t.
cl_v	the road segment that v is currently in.
CR_v	the current route of v.
$group(v)$	the group that v belongs to.
$ind(l,R)$	the index of l in R.
$jf_v^{(i)}$	the GPS position of the i'th junction ahead of v along CR_v.
jb_v	the GPS position of the first junction behind v along CR_v. In another word, it is the entrance of cl_v.

Vehicle v_o may benefit from a message only if the message informs it of a congested road segment downstream along its current route.

Definition 1: effective hit (eff-hit) — A CW message causes an effective hit to a vehicle v_o, if and only if the road segment described by the message, denoting l_k, is in v_o's route CR_{v_o} and $ind(cl_{v_o}, CR_{v_o}) < ind(l_k, CR_{v_o})$.

Definition 2: CW message format: $CW = \{a, t, p_{v_a}^t, k, \tau\}$. a is the ID of originator v_a; t is a time stamp; k is the congested road ID and τ is the travel delay corresponding to l_k.

A message is further encapsulated in a bundle.

Definition 3: bundle format: $bundle = \{f, CW, hc\}$. f is the ID of the forwarder v_f; hc is the hop count of the CW.

C. Carry Strategy

Assuming that v_o overhears a $bundle = \{f, CW, hc\}$ at t_{now}, in which $CW = \{a, t, p_{v_a}^t, k, \tau\}$, the vehicle's Carry Decision is made by Procedure 1 shown in Fig. 1.

Firstly, the Carry Decision Procedure verifies whether the message expires by the value of $k \cdot \lambda^{\Delta t}$. λ is a time decay factor and k is a constant. After that, v_o's action depends on its position.

Procedure 1 Carry Decision Procedure

IF $k \cdot \lambda^{t_{now}-t} > eff\_thresh$
    IF $\angle(\overrightarrow{jb_{v_a} jf_{v_a}^{(1)}}, \overrightarrow{jb_{v_a} p_{v_o}^{t_{now}}}) < \phi$
        IF $hc == 0$
            Put (CW, hc) *in Cache*
        END IF
    ELSE
        IF $\angle(\overrightarrow{jb_{v_a} p_{v_o}^{t_{now}}}, \overrightarrow{p_{v_o}^{t_{now}} jf_{v_o}^{(2)}}) < \varphi$
            Put (CW, hc) *in Cache*
        END IF
    END IF
END IF

Figure 1. Pseudo code of DAGR's Carry Strategy.

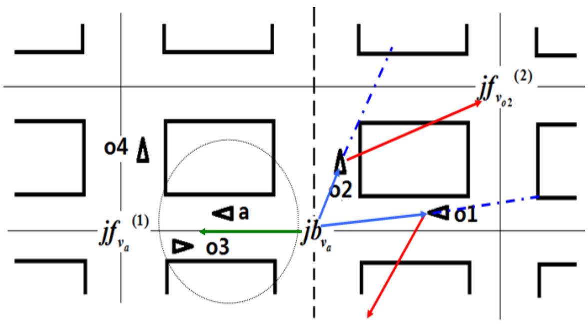


Figure 2. Illustration of Carry Decision Procedure.

As illustrated in Fig. 2, supposing v_a is the CW originator, vehicles on the left side of the dotted line, e.g., v_{o3} and v_{o4}, cannot be effective-hit by this CW because they are not bound for the congested road segment l_k. The procedure may still choose v_{o3} as a relay since it's a 1-hop neighbor of v_a traveling in the opposite direction. The relative position of v_o is measured by the angle between vector $\overrightarrow{jb_{v_a} jf_{v_a}^{(1)}}$ (direction of l_k, green arrow) and vector $\overrightarrow{jb_{v_a} p_{v_a}^{t_{now}}}$ (blue arrow). ϕ is the position angle threshold to determine that v_o is on the left part or the right one. If v_o is on the right side (v_{o1} and v_{o2}), its direction need to be taken into consideration. We adopt the definition of direction in [5], which is a vector from the current location to the 2nd junction downstream v_o's route, denoting $\overrightarrow{p_{v_o}^{t_{now}} jf_{v_o}^{(2)}}$. Abstractly, CW messages are disseminated radially from v_a. If the angle between $\overrightarrow{jb_{v_a} p_{v_o}^{t_{now}}}$ (blue dotted line) and $\overrightarrow{p_{v_o}^{t_{now}} jf_{v_o}^{(2)}}$ (red arrow) is greater than the direction angle threshold φ, it is not necessary to carry the message because v_o is moving toward congested road's entrance jb_{v_a} and vehicles it's about to encounter are likely to have received the message. Otherwise, v_o should carry the message when it is moving away from jb_{v_a}. The angle α between vector $\vec{A}$ and vector $\vec{B}$ is given by

$$\alpha = \arccos\left(\frac{\vec{A} \cdot \vec{B}}{|\vec{A}| \cdot |\vec{B}|}\right) \tag{1}$$

D. Broadcast Strategy

As approaching current road's exit $jf_{v_o}^{(1)}$, v_o processes CW messages it has cached by the Procedure 2 shown in Fig. 3. Denoting $t_{cl_{v_o}}$ the time when v_o entered cl_{v_o}; N_{v_o} is v_o's 1-hop neighbor set. Each element of N_{v_o} has a structure of (u, t_u), where u is the neighbor's ID and t_u is the time when u entered N_{v_o}.

Procedure 2 Broadcast Procedure

FOR EACH (CW, hc) **in** *Cache*
    IF $k \cdot \lambda^{t_{now}-t} > eff\_thresh$
        FOR EACH (u, t_u) **in** N_{v_o}
            IF $group(u) == group(v_o)$ **AND** $t_u > t_{cl_{v_o}}$
                Broadcast $bundle = \{o, CW, hc+1\}$
                BREAK
            END IF
        END FOR
    ELSE
        Drop (CW, hc) **from** *Cache*
    END IF
END FOR

Figure 3. Pseudo code of DAGR's Broadcast Strategy.

The Broadcast Procedure takes vehicle's rational selfishness into consideration. After verifying that the cached CW does not expire, v_o iterates its 1-hop neighbor set to check whether there is any vehicle from the same group in vicinity (the first condition at line 4, Public vehicles bypass this step). If the test is positive, a broadcast attempt is initiated.

The second condition $t_u > t_{cl_{v_o}}$ is to avoid the situation where v_o and u might have kept their 1-hop neighbor relationship for a long time and v_o could broadcast one message repeatedly for u even though u has received it successfully before.

The contention-based broadcasting mode described in [10] is further introduced in case that several vehicles holding the same CW messages might do the broadcasting repeatedly at one junction. Under such circumstance, vehicles would suppress their broadcast attempt if the CW message it was going to broadcast is just overheard.

IV. Evaluation

Mobility decision and message dissemination are influenced by each other in Dynamic Routing. To study the CW dissemination performance and its impact on vehicles' trip-time, we evaluate DAGR on an integrated simulation platform consisting of traffic simulator *sumo* [11] and network simulator *ns2*, which two are coupled through *TraCI* protocol.

A. Simulation Tools

Fig. 4 shows the simulator architecture. To achieve synchronization between two simulators, *ns2* which acts as a *TraCI* client, sends SIMSTEP commands constantly to trigger the simulation process of *sumo* from step k-1 to step k. Then *sumo* sends back all equipped vehicles' Cartesian coordinates to *ns2*. The latter updates all *ns* nodes' destination positions and start the network simulation process of step k. *sumo* keeps the map between vehicle's *sumo* node ID and *ns* node ID [12].

B. Simulation Setup

The simulation is focused on two aspects: 1. DAGR's forwarding efficiency. 2. Vehicles overall trip-time improvements.

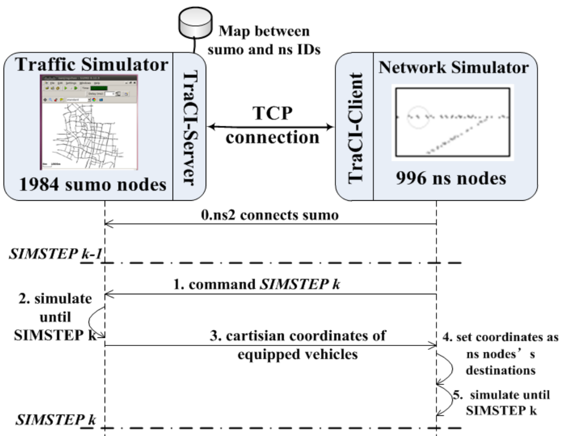


Figure 4. Architecture of *TraCI* simulation environment [12].

The scenario is based on the map of Nanjing, Jiangsu province, China, from *OpenStreetMap* project [13]. It covers 8500m×9500m downtown area of the city, containing 267 junctions and 731 road segments. The speed limit of each road segment is greater than 40km/h. 996 out of the total 1984 vehicles are equipped with SRDs. These equipped vehicles are divided into 1 Private vehicle group, 1 Public vehicle group and 2 Group vehicle groups. DAGR and Convention strategies are tested respectively in the same scenario to compare their performance on the effective-hit numbers and forwarding overheads.

1) Convention Strategy: All equipped vehicles will carry every message they overheard and broadcast them at every junction before these messages expire. It's a brutal but classic strategy, adopted by many researches (like [1][2][6]) to achieve a high delivery ratio. In the simulation, this strategy gives an upper bound in terms of effective hit number.

2) DAGR Strategy: As described in Section III, Private vehicles carry and forward nothing and only do rerouting with CWs overheard; Public and Group vehicles apply Procedure 1 and 2 in their Carry and Broadcast processes.

Before the simulation starts, departure and destination of each vehicle are generated randomly. The straight line distance between two points must larger than 4000m. This guarantees enough traffic crossing the city. The departure time of vehicles is set between 1—200s uniformly, which means there are about 10 vehicles depart per second. Road travel delay threshold is set to 150s, about 3 times of the traffic light duration, which means that if one fails to pass a road segment in two green-light periods, a conclusion can be drawn that congestion happened. Taking the scenario map size and road segment length into consideration, for simplicity the usual ns2 802.11b (with TwoRayGround propagation model) is used. The receiving threshold is adapted to achieve a transmission distance of 300m. As to the message expiration, time decay factor is set to 0.98 and threshold is set to 0.05 to keep the life time of a message at about 150s, which is the travel delay threshold. Other simulation parameters are listed in Table II.

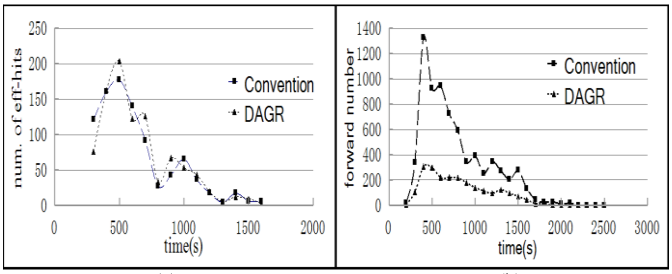
TABLE II. Simulation parameters

Parameter name	Value
OS version	ubuntu 10.04
sumo version	0.12.3
ns2 version	2.34
Vehicle number	1984
Non-equipped vehicle number	988
Private vehicle (G0) number	575
Public vehicle (G1) number	131 (Including 35 route-fixed buses)
Group vehicle (G2) number	194
Group vehicle (G3) number	96
Traffic light duration	45s
Position angle threshold	90 degree
Direction angle threshold	90 degree

C. Dissemination Efficiency

In Fig. 5, we plot the number of effective hits and forwarding attempts for Convention and DAGR, respectively. As we see, DAGR achieves almost the same number of effective hits as that of Convention with only 31.5% of its forwarding overhead. In total, DAGR got 912 effective hits with 2276 forwards while Convention got 936 effective hits with 7210 forwards. Furthermore, if we define Forwarding Efficiency (FE) of a vehicle group G as the average number of effective hits caused by a single forward that vehicles of G make.

$$FE = \frac{num.\ of\ effhitscausedby\ G}{num.\ of\ \ fwds\ G\ has\ made} \qquad (2)$$



(a) (b)

Figure 5. Effective hits and forward numbers of Convention and DAGR: (a) number of effective hits.(b)number of forwards

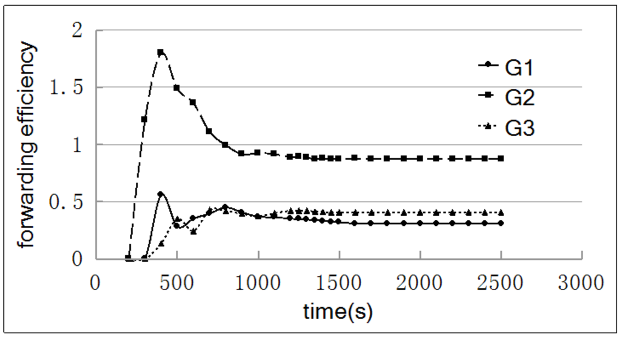


Figure 6. Forward Efficiency of vehicle groups in DAGR

Fig. 6 shows how each group's forward efficiency changes with time. We note that the most influential factor of the forward efficiency is group size instead of vehicle groups' different carrying and broadcasting strategies. Public vehicles in group G1 broadcast CW messages in every road segment before they expire, while vehicles in group G3 broadcast only when there are partners from the same group in vicinity. Yet, such a selfish strategy in broadcasting does not diminish forwarding efficiency. More specifically, each forward of vehicles in G1 result in 0.31 effective hit, in G3 result in 0.4 effective hit and in G2 result in 0.87 effective hit.

As discussed before, vehicles may use messages overheard from other groups. We call this spillover effect. To understand how broadcasting strategy influence spillover effect, we define spillover ratio as:

$$spilloverratioof\ G = \frac{effhitcausedby\ G - G's\ effhitcausedby\ G}{effhitcausedby\ G}. \qquad (3)$$

The spillover ratio of G1, G2 and G3 is 11.5, 3.08 and 5.38 respectively. This means among every 12.5 effective hits caused by G1 vehicles, 11.5 hits are contributed to vehicles of other groups. It seems that Public vehicles do more for public welfare. However, if we look each group's FE again, the largest group G2 with a 0.87, still contributes 0.87×3.08/(1+3.08)=0.66 effective hit to other groups per forward, higher than G1's 0.23 and G3's 0.34.

D. Trip-Time Improvement

We evaluate the trip-time gain/loss of our model with metrics named Trip-Time Decrease/Increase Ratio, defined in CATE [9]. Fig. 7 shows the comparison between CATE and DAGR. *oldtime* refers to vehicle's trip-time when Dynamic Routing is not used and *newtime* refers to the one when Dynamic Routing is adopted. The Decrease Ratio is defined as ratio=*oldtime/newtime*. Obviously, the greater this ratio is, the more time Dynamic Routing saved. Similarly, Increase Ratio is defined as ratio=*newtime/oldtime*. If the variation of this ratio is within ±10% trip-time, we think the vehicle is not affected in terms of trip-time.

The trip-time saving effect of Dynamic Routing is not as significant as we used to expect. As we may see, most vehicles in both models get either a slight improvement (33% in CATE and 16% in DAGR, ratio less than 1.25) or no improvement (23% in CATE and 45% in DAGR, not drawn in histograms). CATE's performance seems to be slightly better than DAGR and their distribution are roughly consistent. One point that should be kept in mind is that, since CATE adopts a replica-based forwarding mechanism while DAGR is a geo-based algorithm, they are two orthogonal techniques and may be combined to achieve a better performance.

V. CONCLUSION AND FUTURE WORK

A. Conclusion

Through discussion and simulation above, we can conclude that in Dynamic Routing, Direction-Assisted Geographic Relay can decrease forwarding overhead dramatically without sacrificing dissemination performance compared with Convention forwarding strategy. In addition, we also find that the group size is the most influential factor of forwarding efficiency despite of different forwarding strategies of vehicle groups. Even if we take spillover effect into consideration, vehicles from large-size groups still make more contributions to the total effective hit gain. As to the trip-time improvement, nearly 25% of vehicles notably benefit from Dynamic Routing while the trip-time of the rest remains almost unchanged (±25% trip-time).

B. Future Work

The DAGR model in this paper is specially tailored for Dynamic Routing and may not support other vehicular network applications, especially those requiring a high real-time performance and cooperation between vehicles, such as traffic safety applications. To build a general dissemination model is a very challenging and meaningful task and certainly a lot of factors about performance, security and privacy need to be taken into consideration.

During the simulation, we set two DAGR's angle thresholds to an intuitive value $\phi = \varphi = 90^o$. Whether it is an optimal choice still needs to be investigated, both theoretically and experimentally. Furthermore, the urban scenario still needs more improvements and different ratios of vehicles will be evaluated to figure out how these parameters influence the system performance.

Last but not least, messages from other groups may not be trusted completely in real life for security considerations. Trust management between different vehicles is still an unsolved problem. Some trust models for vehicular network have been proposed, but they still need to be tailored for specific applications and their effectiveness yet need to be evaluated in realistic scenarios.

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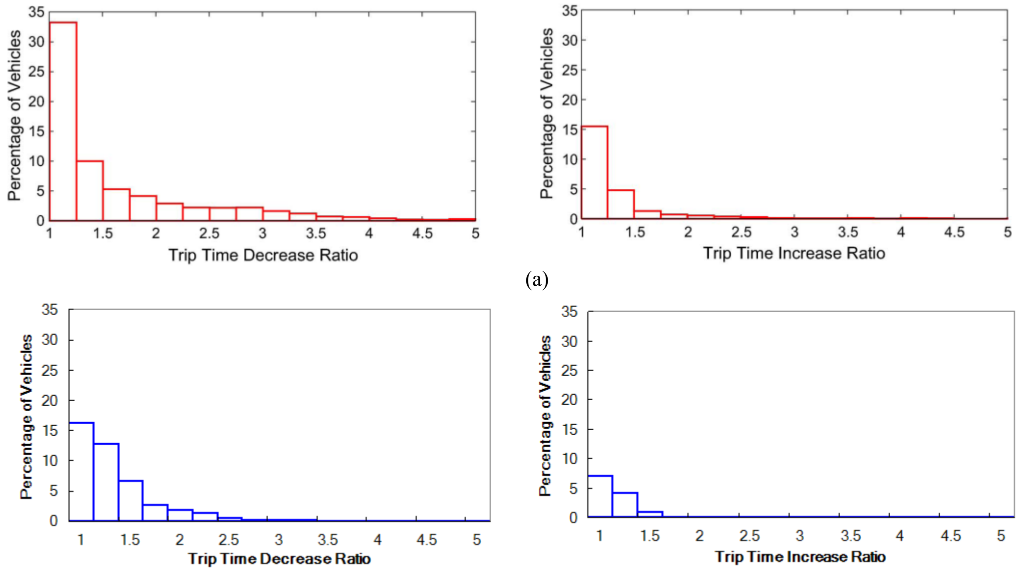

(a)

(b)

Figure 7. Trip-time improvement of CATE [9]and DAGR:
(a) Histogram of CATE’s trip-time gain/loss. (b) Histogram of DAGR’s trip-time gain/loss