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Cloud-Assisted Safety Message Dissemination in VANET-Cellular Heterogeneous Wireless Network

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***Abstract*—In vehicular ad-hoc networks (VANETs), efficient message dissemination is critical to road safety and traffic efficiency. Since many VANET-based schemes suffer from high transmission delay and data redundancy, integrated VANET-cellular heterogeneous network has been proposed recently and attracted significant attention. However, most existing studies focus on selecting suitable gateways to deliver safety message from the source vehicle to a remote server, while rapid safety message dissemination from the remote server to a targeted area has not been well studied. In this paper, we propose a framework for rapid message dissemination that combines the advantages of diverse communication and cloud computing technologies. Specifically, we propose a novel Cloud-assisted Message Downlink dissemination Scheme (CMDS), with which the safety messages in cloud server are first delivered to the suitable mobile gateways on relevant roads with the help of cloud computing (where gateways are buses with both cellular and VANET interfaces), and then being disseminated among neighboring vehicles via vehicle-to-vehicle (V2V) communication. To evaluate the proposed scheme, we mathematically analyze its performance and conduct extensive simulation experiments. Numerical results confirm the efficiency of CMDS in various urban scenarios.**

***Index Terms*—Vehicular ad-hoc network (VANET), Cloud computing, VANET-cellular network, Safety Message, Data downlink dissemination.**

I. INTRODUCTION

Nowadays, the advances in Vehicular Ad-hoc Network (VANET), Mobile Cloud Computing (MCC) and Cyber-Physical System (CPS) have given birth to the concept of Vehicular Cyber-Physical Systems (VCPS), boosting a growing interest in the design, development and deployment of VCPS for some emerging applications. A typical application in VCPS is to disseminate safety and traffic messages among vehicles, including accident warning, congestion information, route suggestion, etc., by Dedicated Short Range Communication (DSRC) based VANETs. In general, such VANETs provide two types of wireless communications, vehicle-to-vehicle (V2V) communication and vehicle-to-infrastructure (V2I) communication, respectively. Based on them, many VANET-based message dissemination schemes have been developed.

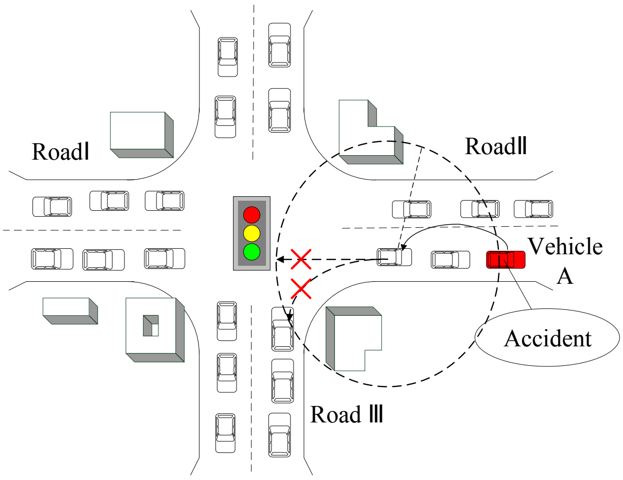

Fig. 1. An example of message delivery in traditional VANET.

Although these VANET-based schemes are viable, it is still challenging to timely and reliably disseminate messages to a targeted area under the inherently intermittent vehicular networking environment, due to the limited transmission range of DSRC as well as the contention-based carrier-sense multiple access with collision avoidance (CSMA/CA) scheme in IEEE802.11p protocol. This problem becomes even worse in urban scenarios for the conventional broadcast schemes such as flooding and store-carry-forward [1].

As illustrated in Fig. 1, vehicle **A** on road **II** suffers from an accident and transmits an accident warning to vehicles on road **II**. However, due to the bad wireless channel condition, a vehicle on road **II** cannot further disseminate the safety message to vehicles on road **I** and **III** by using IEEE802.11p. As a result, vehicles on **I** and **III** may enter into road **II** and suffer traffic congestion.

For long-distance dissemination of safety messages, a better solution is the cellular network. Thus the above problem can be partly solved with the assistance of the integrated VANET-cellular heterogeneous networks [2]–[7]. In [2], for example, the authors put forward a VANET-3G integrated network architecture, in which vehicles are clustered based on different parameters. In these clusters, those vehicles equipped with 3G and IEEE802.11p interfaces are elected as gateway candidates

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to connect local VANETs to Internet and, accordingly, transmit safety messages to the remote server. Therefore, through the mobile or stationary gateways that can provide Internet access, the message transmission coverage can be further extended.

Despite the importance of the existing solutions, we first note that there is lack of data downlink dissemination strategy indicating how to rapidly deliver the safety message from the remote server to the vehicles in targeted area. In fact, this is a complicated work for traditional VANET-based centralized solution [8]. Currently, the efficient urban transportation management requires massive traffic data, such as sensors and videos, distributed in large urban areas, which cannot be handled by the sole VANET technology and traditional centralized intelligent transportation systems. More servers are required in different regions to collect the instantaneous traffic information. Secondly, when a traffic accident happens somewhere, it is important to make timely decision of the targeted areas and vehicles for message dissemination to avoid traffic congestion. Thus the distributed servers need to cooperately determine the targeted areas and desired receivers. In this circumstance, a cloud-assisted VANET solution will be a more flexible and effective choice to solve the problem of downlink strategy [9], [10].

In the past few years, cloud computing has been widely adopted to help handle complicated computing work that can hardly be accomplished locally [11]. The combination of VANET and cloud computing has propelled our capability even further [4], [12]–[15]. Generally speaking, the mobiles could upload to delegate time-consuming and energy consuming tasks to clouds [12]. Cloud-assisted VANET can acquire instantaneous traffic flows, have macro-control of the geographical position of all vehicles, make an accurate assessment of the cause of the congestion and traffic flow, and determine the targeted area and desired recipients [16]. Therefore, it can send the safety message containing the position of accident scene, severity of accident, the estimation of accident duration and even different route to vehicles distributed in different areas.

In this paper, we propose a cloud-assisted safety message dissemination framework for an integrated system that consists of both cloud infrastructure and VANET-cellular heterogeneous wireless networks. Specifically, we consider an integrated VANET-cellular network where the buses act as mobile gateways. Cloud servers, on the other hand, can acquire instantaneous traffic flows data and the geographical position of all mobile gateways, and hence efficiently deliver important traffic information (traffic accident, route recommendation, etc.) to the vehicles in the targeted area. In our framework, a bus-based network is a practice solution as wireless backbone in an urban scenario for the following reasons: Firstly, governments do not need to pay upfront cost to deploy a large quantity of infrastructures. In fact, many buses nowadays access Internet with their cellular devices [17]. Secondly, a public transportation system provides access to a large set of users (e.g., the passengers themselves) and is already designed to guarantee the coverage of the urban area. Finally, travel times can be predicted from the transportation system time table [18].

In our framework, the data downlink dissemination strategy is implemented by two steps. The first step is to disseminate messages from a cloud server to suitable gateways. The cloud server makes an accurate assessment of the traffic flow and determines the targeted area, and then determines the suitable mobile gateways which the safety messages are transmitted to. The second step is to deliver messages from the gateways to targeted vehicles, which can be implemented via V2V communication. Specifically, to reduce packet loss and redundancy caused by broadcasting, we design a distributed approach to select the delegators forward and backward. The proposed scheme can not only disseminate messages efficiently and rapidly, but also significantly reduce the cellular communication cost, which is more easily accepted by users.

Our main contributions in this paper are threefold. 1) Based on cloud computing technology, we propose a VANET-cellular heterogeneous architecture in which buses are considered as mobile gateway providers. 2) We propose a Cloud-assisted Message Downlink dissemination Scheme (CMDS), indicating how cloud server disseminates the safety messages to desired vehicles. Specifically, we design a parallel multi-point message dissemination approach to locally broadcast safety messages among vehicles, which can significantly reduce packet loss and message redundancy. 3) We analyze the dissemination delay until all the desired vehicles receive the safety messages. This analysis can help to know how to reduce the delay more efficiently.

The rest of this paper is organized as follows. We first discuss the related work in Section II. The main approach for safety message dissemination will then be presented in Section III. Based on this approach, we mathematically analyze the performance in Sections IV. We validate our analysis through simulation in Section V, before concluding the paper in Section VI.

II. RELATED WORK

In the literature, existing message dissemination strategies can be classified into two categories according to the transmission medium: VANET-based scheme and integrated VANET-cellular heterogeneous scheme [19]. In addition, cloud technologies have recently been adopted in some message dissemination schemes. In the rest of this section, we will discuss them one by one.

A. VANET-based Message Dissemination

In the first category, the messages are disseminated in VANETs with a store-carry-forward manner, where vehicles exchange data packets when they are within the communication range of each other. In [20], the farthest neighbor node is selected as the relay to transmit the safety message. However, this scheme may suffer from a high packet error rate (PER) and a large path loss. As a result, the message retransmission would waste time and bandwidth especially in a high density traffic environment. The cross layer broadcast protocol (CLBP) in [21] used the metrics of geographical locations, channel condition and velocities of vehicles to select an optimal relaying vehicle node. Analytical and simulation

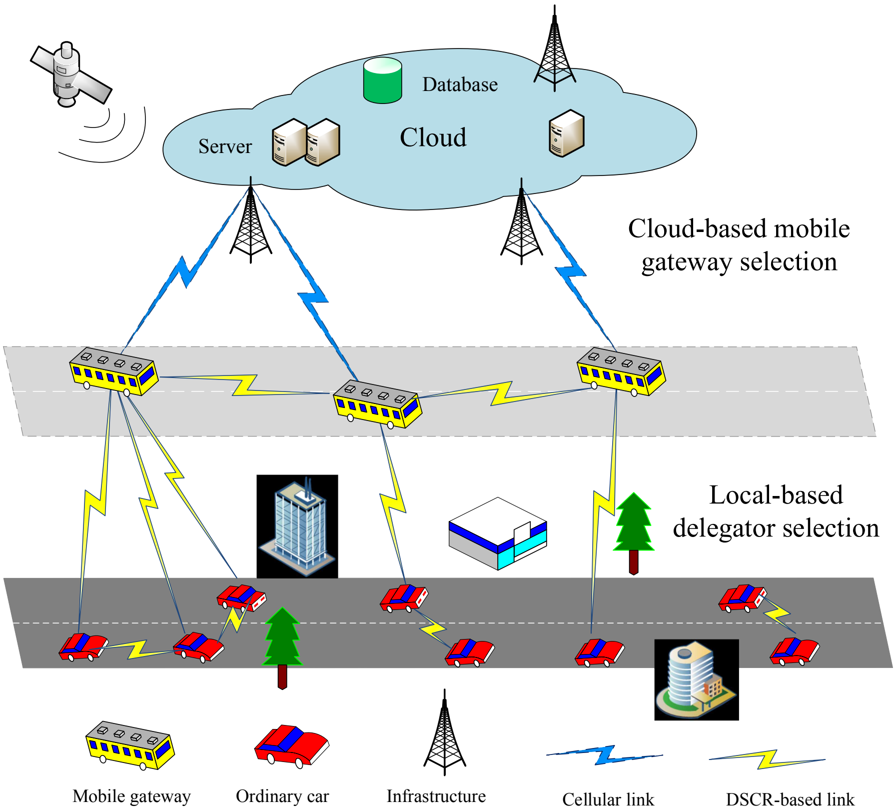


Fig. 2. Architecture of cloud-assisted VANET-cellular heterogeneous wireless networks.

results showed that the proposed cross-layer approach can quickly and reliably deliver emergency messages while minimize the broadcast message redundancy. However, for the pure VANET-based message dissemination, the transmission delay may significantly increase in sparse traffic scenarios and the system performance cannot be guaranteed.

B. Integrated VANET-cellular Heterogeneous Message Dissemination

In the second category, safety messages are first transmitted to Internet through gateways and then be delivered to the vehicles in the targeted area. With the extensive deployments of 3G/4G base stations, researchers begin to concentrate on gateway selection approach to connect VANET to the Internet. In [2], the authors put forward a VANET-3G integrated network architecture in which vehicles are clustered based on different parameters. In these clusters, those vehicles equipped with 3G and IEEE802.11p interface cards are elected as gateway candidates to connect VANET to Internet. In [3], the authors proposed gateway selection method considering traffic priority first, with the purpose of ensuring the Quality of Service (QoS) of different traffic data. Nevertheless, we note that most of the existing studies focus on the uplink strategy which indicates how to select a suitable gateway by source vehicle to upload message to a server, while the downlink message dissemination strategy is seldom considered. In [22], thr authors first put forward Connection Stability Aware Partner-based Hierarchical Mobile IPv6 (CSA-PHMIPv6) in which mobile nodes select partners with whom communication can last for a sufficiently long time by employing the Link Expiration Time (LET) parameter.

C. Cloud-Assisted Message Dissemination

The development of cloud computing technology brings means to the message dissemination in VANET, and gives birth to the concept of vehicular cloud computing. In [23], the authors proposed a framework which aims at smooth migration of all or only a required portion of an ongoing IP service between a data center (DC) and user equipement of a 3GPP mobile network to another optimal DC with no service disruption. In [24], the author also discussed the challenges these trends present to mobile network operators, and demonstrated the possibility of extending cloud computing beyond data centers toward the mobile end user, providing end-to-end mobile connectivity as a cloud service. In [16], Olariu *et al.* proposed the idea of vehicular clouds by taking traditional VANET to the clouds. The motivation is that the massive sensors deployed on vehicles, streets as well as parking area provide abundant communication and computational resources, which could potentially bring benefits to the resource providers as well. But they did not discuss the potential structural framework for vehicular clouds. In [25], the authors put forward, for the first time, the taxonomy of future VANET clouds. Additionally, they also discussed the challenges of the security and privacy in VANET clouds. In [26], three types of vehicular computing are described: Networks as a Service (NaaS), Storage as a Service (STaaS) and Data as a Service (DaaS). The core concept of NaaS is that the cloud collects the information of the vehicles which prefer to offer Internet access service, thus the cloud can provide the most suitable connection to the vehicle whenever needed. Researchers in [27] designed a system to help vehicles search for mobile cloud servers that are moving nearby and discover their services and resources. The system leverages the RSUs as cloud directories to record mobile cloud servers registration. The RSUs share their registration data to enable vehicles to discover and consume the services of mobile cloud servers within a certain area.

III. CLOUD-ASSISTED SAFETY MESSAGE DISSEMINATION SCHEME

In this section, we elaborate on the proposed cloud-assisted VANET-cellular architecture for rapid safety message dissemination as well as its critical functions.

A. The Architecture

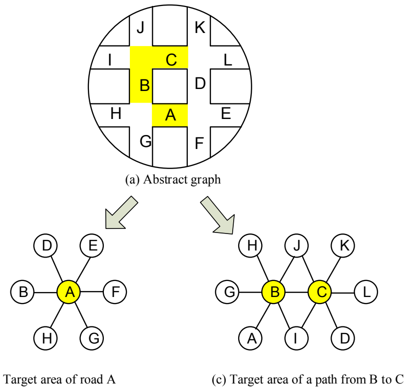
Fig. 2 shows the proposed architecture of cloud-assisted VANET-cellular heterogeneous wireless networks. The architecture consists of three tiers of nodes. The low-tier nodes are the ordinary vehicles which collect instantaneous traffic information and broadcast it to local area only by using IEEE 802.11p protocols. The high-tier nodes are the distributed cloud servers which can provide timely traffic information and suitable traffic guidance. The mid-tier nodes, namely Gateway Service Providers (GPs), are the buses which provide Internet accessing service and exchange information between the Internet and the neighboring vehicles. Therefore, GPs should support both cellular communication and IEEE 802.11p protocols, being registered to clouds.

The general message dissemination process under the proposed architecture is as follows. At the beginning, the GPs which are willing to provide Internet access should dynamically report to the cloud their basic information such as geographic coordinates, access delay, bandwidth, etc. Also, the GPs should broadcast this basic information to their neighbors so that they can get a list of surrounding gateway providers. The ordinary vehicles could send the safety message to the cloud through the selected gateways. Then, the cloud send the message to the gateways in the targeted area, which will then disseminate the message to vehicles around.

To implement the message dissemination process, some preliminaries, including gateway registration and targeted area definition, are required. In addition, gateway decision and message broadcasting among vehicles are the critical steps for the message dissemination. All of these schemes are addressed as follows.

B. Preliminaries

1) Gateway Registration: In our design, a GP candidate creates a registration packet containing its basic information: (a) Movement information including geographical position, velocity, and moving direction. (b) Networking information such as connected networking type (LTE, 3G, Wi-Fi and WiMAX) [26], receive signal strength, as well as the networking load which indicates the number of vehicles to be served by the GP.



(a) Abstract graph

(b) Target area of road A

(c) Target area of a path from B to C

Fig. 3. Targeted area definition.

Firstly, The GP candidates send the packet to the cloud. Then, the cloud records the related information in the database of Gateway Pool, and sends back a Gateway ID (GID) to the registering GPs. The GPs should periodically report their status to the cloud [28].

Based on the information from vehicles and sensors, the cloud can instantaneously construct the gateway location map as well as the traffic matrix [8], and then estimate the road segment traffic loads and delays accordingly.

2) Targeted Area Definition: When an accident happens, vehicles in the targeted area are supposed to receive the safety message which indicates the accident location and the rescheduled route [29]. The targeted area calculation will be a complicated work which should be supported by mass of historical and real-time data. In this paper, we define a targeted area as the roads that are intersecting with the road where accident happens. To better illustrate the definition, we consider two different situations in Fig. 3(a). In case one, a vehicle on road A is assumed to suffer from an accident. Cloud would preferentially send the safety message to nearby roads including B, D, E, F, G and H. Similarly, if a fire happens in one building on road K , the fire truck on road H could send a road reservation message to cloud to reserve road B and C. Then cloud will immediately disseminate the message to vehicles on road A, G, H, J, K, L, D and I. In these two situations, cloud should make a rapid and precise decision so that the accident could be solved in a most efficient way.

In Fig. 3(b) and Fig. 3(c), each node represents a road and there is an edge between two road segments if they are intersecting. If a shortest n-roads path is calculated by the Dijkstra algorithm with each road having the same weight, We can derive that the targeted area of this path contains $6 + 2(n - 1)$ roads.

C. A Cloud-Based Approach to Select the Mobile Gateways

Intuitively, the cloud should disseminate the safety message to the gateways which are evenly distributed on the road so that all the vehicles can acquire the message from nearby gateways directly. However, due to irregular traffic flow, gateways are normally unevenly distributed in geographical areas

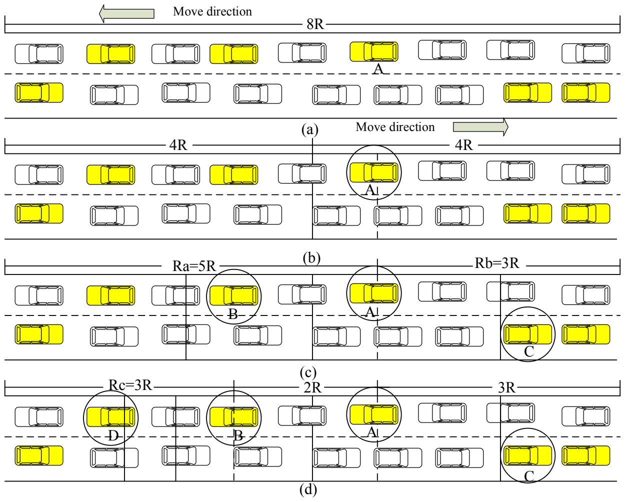


Fig. 4. Gateway selection approach by cloud.

in practice. Therefore, the cloud, which has the real-time traffic density and gateways distribution, should choose the gateways whose transmission range can cover more vehicles on the road and avoid two gateways being too close at the same time.

We assume that there are 8 gateway candidates running on an $8R$-meters road, as shown in Fig. 4(a). In addition, all vehicles have an identical maximum transmission range of R when they communicate to each other using IEEE 802.11p protocols. The detail of selection method can be described as follows.

1) Firstly, we divide the road into two parts with equal distance and select the vehicle A as gateway provider which is nearest to the middle point of the road, as shown in Fig. 4(b).
2) Secondly, in Fig. 4(c), we take the position of vehicle A as the splitting point and divide the road into two segments RS_a and RS_b , then cut the two road segments into two parts with equal distance. Likewise, we select the vehicles B and C as gateway providers which are nearest to the middle point in these two parts.
3) At last, as shown in figure Fig. 4(d), we take B and C as the splitting point and continually divide the road. As the length of the left road segment of vehicle B is more than $2R$, it should do the same step as step (2). Thus vehicle D is selected as the last vehicle gateway.

After the procedure of gateway selection, vehicle A, B, C and D are selected as gateways which will receive the safety message from the cloud subsequently.

D. A Distributed approach to select the Delegator Forward and Backward

In the previous study, researchers mostly assume that the safety message is sent by only one vehicle, named the source vehicle, and design the corresponding broadcast protocol. Also, most studies address the issue of message dissemination on merely one road. Situation will be very different in cloud-based VANET environment. After the cloud receives the safety message, it will deliver the message to several suitable gateway vehicles, as stated previously. The problem is that how these gateway vehicles can deliver the message to the vehicles nearby with lower transmission delay and less data redundancy, which is regarded as a critical issue in cloud-based VANET environments. To the best of our knowledge, such an issue has not been fully studied so far.

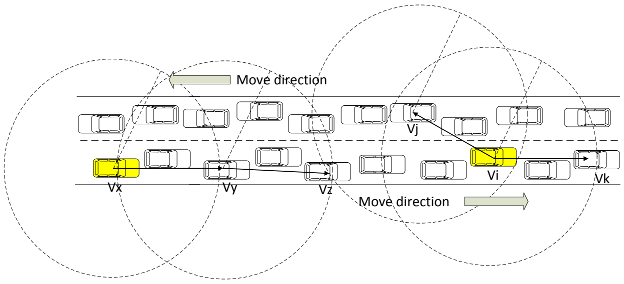


Fig. 5. A distributed delegator selection approach.

In this paper, instead of only considering one road, a parallel multi-point safety message dissemination approach is proposed from an overall perspective of road, aiming to maximize the broadcast coverage area and minimize the date redundancy and transmission delay. Our approach is based on the following common observation: Vehicles driving on the same direction are relatively static to each other. Even if a disseminator keeps broadcasting the message, few new vehicles can be reached. Therefore, we consider that gateways should relay the “disseminator role” to the farthest receiver forward and backward after broadcasting the safety message, which ensures that the remote vehicles can acquire the safety message immediately. Since some gateways may broadcast the message at the same time slot, the delegator selection process of the gateway should be terminated when the vehicles in front are detected that they have already received the safety message, thus data redundancy could be reduced significantly.

As shown in Fig. 5, it is assumed that vehicle V_i and V_x are selected as the gateways to disseminate the message. V_i prefers to choose vehicle V_k, which is the farthest one within the transmission coverage and moves in the same direction, as the forward delegator. On the other hand, V_j that is farthest from V_i at the back will be selected as the backward delegator. Likewise, V_x would choose V_y as its forward delegator. V_y detects the vehicles ahead have not receive the message and continue to select the delegator. However, when V_j finds that the vehicles ahead have already received the message from V_z, the delegator selection process of V_i will stop. The concrete implementation of delegator selection method will be introduced as follows.

When a gateway receives the safety message, it broadcast the message rapidly, along with its basic information including velocity, geographical position, and moving direction. c_dir and r_dir are the moving direction of current broadcast vehicle and receiver vehicle. The nearby vehicles will reply a message to indicate the gateway to stop the delegator selection process if they have already received the safety message from other gateways. Otherwise, they will decide the time T_w to send a feedback message [30]. The gateway will choose the vehicle, which replies the feedback message the earliest, as the delegator, and send a confirm message to it.

As mentioned above, the vehicle farthest from the gateway within the transmission range has the highest priority as the delegator. Another factor we consider is the relative velocity. a lower relative velocity means a more stable link between the source vehicle and the delegator candidate. So a relaying metric F that is used to calculate T_w is given by:

$$F = \alpha_1 \left(1 - \frac{\Delta d}{D\max}\right) + \alpha_2 \left(\frac{\Delta V}{2V\max}\right) \tag{1}$$

where Δd is the distance between the current broadcasting vehicle and one delegator candidate within the transmission range, $D\max$ denotes the maximum of Δd, ΔV is the relative velocity between the current broadcasting vehicle and one delegator candidate, $V\max$ denotes the maximum of ΔV, α_1 and α_2 are the weight factors that are configured by vehicle, $\alpha_1 + \alpha_2 = 1$. For instance, vehicles are relatively steady in a high density traffic environment, it can set a larger α_1 so that the message can be delivered more faster. Otherwise, a larger α_2 can be set, so that packet error rate(PER) of message delivery can be reduced.

The calculation of T_w can be referred to [31] in which the concept of minislot is proposed. The length of minislot is τ, then we divide the Distributed Inter-frame Spacing (DIFS) interval into k number of minislots, and partition the value of $F_{max} - F_{min}$ into k segments at the same time. The value e_0 of each segment is $(F_{max} - F_{min})/k$. Thus value of T_w will be set as i minislots, if the metric of F is within $[F_{max} + (i-1) \cdot e_0, F_{min} + i \cdot e_0]$, where $i \in [1, k]$. However, the collision may occurs if the delegator candidates select the same minislot. In this case, it will continue to divide e_0 into k segments, each of which being $e_1 = e_0/k$, and then the vehicle chooses a minislot and start the back-off stage again. The preudocode of delegator selection is shown in Algorithm 1.

The delegator will repeat the same procedure as gateway vehicle. However, there is no need to select the delegator in the opposite propagation direction. In most cases, there are a large numbers of buses moving on the roads in city environment, so the buses only need to transmit the safety message in one hop, regardless of the delegator selection. Accordingly, the transmission delay of safety message on these roads will be significantly minimized.

Algorithm 1 Delegator selection algorithm

```
 1: vehicle $V_y$ receive a safety message from $V_x$.
 2: if $V_y$ has received the safety message before then
 3:     send a message to $V_x$ to terminate the delegator selection.
 4: else
 5:     if $r\_dir = c\_dir$ then
 6:         if $V_y$ is in the moving direction of $V_x$ then
 7:             go to line 18.
 8:         else
 9:             set the NAV
10:         end if
11:     else
12:         if $V_y$ is in the opposite moving direction of $V_x$ then
13:             go to line 18.
14:         else
15:             set the NAV.
16:         end if
17:     end if
18:     if $0 < retry < r_{max}$ then
19:         Compute the $F$.
20:         Start the back-off timer.
21:     else
22:         Divide the minislot and map $F$ to one of the minislot.
23:         Start the back-off timer, and go to line 18.
24:     end if
25:     while the back-off timer !=0 do
26:         if $V_y$ receives the feedback message replying the same safety message then
27:             Stop the timer and set the NAV.
28:             break.
29:         end if
30:     end while
31:     if the back-off timer=0 then
32:         Reply a feedback message, and $retry$++.
33:     end if
34:     vehicle $V_y$ receives a feedback message.
35:     if $V_y$ has received the same safety message before then
36:         send a message to indicate $V_y$ to stop selecting delegator in next hop.
37:     else
38:         delete the feedback message.
39:     end if
40: end if
```

IV. MATHEMATICAL ANALYSIS

In this section, we mathematically analyze the dissemination delay of the proposed message dissemination scheme, which is helpful to understand how the safety message is swiftly transmitted to the desired receivers.

A. Problem Definition

Here, we develop an analytical model to analyze the performance of the proposed scheme. To make the proposed scheme mathematically tractable, we have the following assumptions:

1) Vehicles on the single road are poisson distributed, and λ denotes its mean value per meter.
2) The physical channel is reliable and error-free.
3) The identical transmission range is R meters.

Safety message dissemination delay T_A is defined as the time interval from the time that the safety message is formulated in cloud server until the time that all the vehicles in targeted area receive the message. Suppose that the cloud should send the safety message to S roads. Thus, we have:

$$T_A = \max\{T_1, T_2, \ldots, T_s\} \tag{2}$$

where T_i(i=1,2,... s) is the time point when all the vehicles on road R_i receive the message.

Without loss of generality, we consider the time interval TR for one of the roads R. Before the analysis, we first

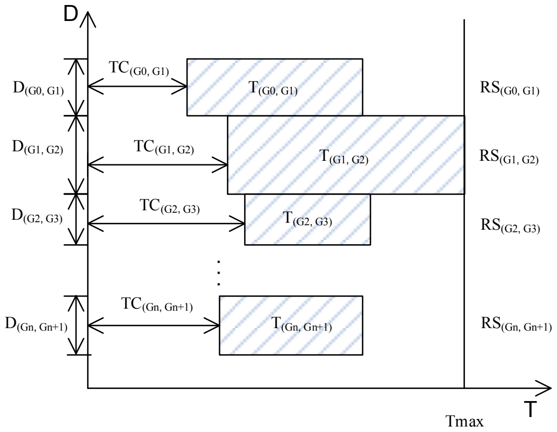


Fig. 6. Safety message dissemination chart.

introduce the following notations. We use G_i(i=1, 2, ...,n) to denote the vehicles that are selected as mobile gateways on the road R. Then road R will be cut into $n+1$ segments denoted as $RS_{(G_i,G_{i+1})}$ respectively. Specially, $RS_{(G_0,G_1)}$ and $RS_{(G_n,G_{n+1})}$ are the first and last segment respectively. $L_{(G_i,G_{i+1})}$ denotes the distance of $RS_{(G_i,G_{i+1})}$. $TS_{(G_i,G_{i+1})}$ is the delay when all the vehicles on $RS_{(G_i,G_{i+1})}$ receive the safety message. $D_{(G_i,G_{i+1})}$ represents the traffic density. We use $W_{(G_i,G_{i+1})}$ to denote the workload of the road segment which represents the number of vehicles to receive the safety message. $W_{(G_i,G_{i+1})}$ can be seen as a constant value in a short time interval.

For better understanding, we depict Fig. 6 in which a analysis charts for a road R is given where $TC_{(G_i,G_{i+1})}$ is the time point when the gateway on this segment receives the safety message from the cloud. As the gateways almost sense the similar signal strength on the same road, we assume in this paper, that the difference of $TC_{(G_i,G_{i+1})}$ in different road segments is small enough that the safety message dissemination on different road segments will not interfere with each other. The workload $W_{(G_i,G_{i+1})}$ in each road segment is represented by a rectangle. The width of the rectangle represents $D_{(G_i,G_{i+1})}$ which is the traffic density of the road segment, and the length represents $T_{(G_i,G_{i+1})}$. So we have:

$$T_{(G_i,G_{i+1})} = TC_{(G_i,G_{i+1})} + TS_{(G_i,G_{i+1})} \tag{3}$$

$$T_{max} = \max\left\{T_{(G_0,G_1)}, T_{(G_1,G_2)}, \ldots, T_{(G_n,G_{n+1})}\right\} \tag{4}$$

where T_{max} is the time when all vehicles on the road R receive the safety message.

We can see from above analysis that a shorter distance of maximum road segment and more disseminators can make contribution to minimize the T_{max}. This is also the theory foundation of the gateway and delegator selection method we proposed in this paper. Our objective is to calculate the TS for one of the road segment, so T_A and T_{max} can be calculated by Eq. (2) and Eq. (4).

B. Average hops between two gateways

Let x denote the random variable of vehicles which enter in a l-meters length road [32]. Therefore the probability mass function(PMF) of x and its expectation can be represented as:

$$P\left(x=n\right) = \frac{\left(\lambda l\right)^n}{n!} e^{-\lambda l} \tag{5}$$

$$E\left(x\right) = \lambda l \tag{6}$$

Let d denote the distance between the adjacent vehicles and it is equal to $v \cdot t$. As the time interval t between the two vehicles is exponential distribution, so we have:

$$P\left(d=k|d \le R\right) = \frac{1-e^{-\left(\frac{\lambda \cdot k}{v}\right)}}{1-e^{-\left(\dfrac{\lambda \cdot R}{v}\right)}} \tag{7}$$

.

$$E\left(d\right) = \frac{v}{\lambda} - \frac{R}{e^{\left(\frac{\lambda \cdot R}{v}\right)-1}} \tag{8}$$

The expected number of neighboring vehicles is:

$$E\left(s\right) = \left\lfloor \frac{R}{E\left(d\right)} \right\rfloor \tag{9}$$

Then the expected hops on a l-meters length road can be calculated as :

$$h(l) = \left\lfloor \frac{E\left(x\right)-1}{E\left(s\right)} \right\rfloor = \left\lfloor \frac{\lambda \cdot l - 1}{E\left(s\right)} \right\rfloor \tag{10}$$

C. Transmission delay in one hop

Here, the transmission delay in one hop T_h is defined as the time interval from the time that the safety message arrives at the head of queue until the time that the delegator is determined and receives the confirm message. It includes:

1) T_{aifs} being the arbitration inter-frame space which can refer to IEEE802.11e.
2) T_{sm} consisting of the back-off time, the frozen time due to other transmission, the retransmissions time caused by the safety message error or collisions, a successful safety message transmission.
3) T_{fm} consisting the retransmission time due to feedback message collisions, and a successful feedback message transmission time.
4) T_{cm} consisting of the retransmission time caused by confirm message collision and successful confirm message transmission time.

So T_h can be calculated as:

$$T_h = T_{aifs} + T_{sm} + T_{fm} + T_{cm} \tag{11}$$

After the gateway obtains the safety message from the cloud, it will choose a back-off timer w and broadcast the message when the timer goes to 0. Thus T_{sm} can be represented as:

$$\begin{aligned} T_{sm} = \sum_{m=0}^{\infty} e^m \left(1-e\right) [& \left(w + tsifs + \frac{l_{sm}}{r_b}\right) \\ & + m\left(w + t_{sifs} + \frac{l_{sm}}{r_b}\right)] \end{aligned} \tag{12}$$

where $e^m(1-e)$ is the probability of the successful safety message transmission after m retransmissions [33]. $w + t_{sifs} +$

$l_{sm}/r_b + m\left(w + t_{sifs} + l_{sm}/r_b\right)$ is the corresponding time taken in the retransmission process.

T_{fm} is calculated by:

$$T_{fm} = F_0 t_0 + \sum_{m=1}^{r_{max}} \left(\prod_{j=0}^{m-1} C_j \right) F_m t_m \tag{13}$$

where C_m, F_m and t_m are the probability of collision of feedback message, the successful transmission of feedback message, and the average time taken for a delegator successfully replying a feedback frame at back-off stage m respectively.

T_{cm} is calculated by:

$$T_{cm} = \sum_{m=0}^{\infty} q_4^m \left(1 - q_4\right) \left[\left(t_{sifs} + t_{cm}\right) + m\left(t_{sifs} + t_{cm\_r}\right)\right] \tag{14}$$

where $q_4^m \left(1 - q_4\right)$ is the probability that the current broadcast vehicle successfully sends a confirm message at back-off stage m, and $t_{sifs} + t_{cm} + m\left(t_{sifs} + t_{cm\_r}\right)$ is the corresponding delay. Since a vehicle could get the feedback message immediately after it broadcasts the safety message in the last hop, the delay T_l in the last hop is less than T, and we have:

$$T_l = T_{sm} + \sum_{m=0}^{\infty} q_4^m \left(1 - q_4\right) \left[\left(t_{sifs} + t_{fm}\right) + m\left(t_{sifs} + t_{fm\_r}\right)\right] \tag{15}$$

Let TS denote the expected safety message transmission delay in a segment and l_s denote the length of the road segment. According to Eq. (10) and Eq. (15), we have:

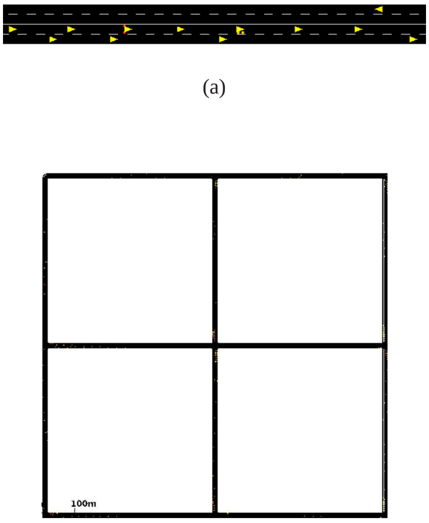
$$T_h \cdot \left[\frac{h(l_s)}{2} - 1\right] + T_l \le TS \le T_h \cdot \left[h(l_s) - 1\right] + T_l \tag{16}$$

V. SIMULATION

In this section, we evaluate the performance of the proposed scheme via OMNeT++ simulator. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators. Road traffic simulation is performed by SUMO, which is well-established in the domain of traffic engineering. To perform IVC evaluations, both simulators are running in parallel, connected via a TCP socket. Movement of vehicles in the road traffic simulator SUMO is reflected in movement of nodes in an OMNeT++ simulation. In particular, we will first explain the simulation settings and then validate the mathematical model developed previously. We will then investigate the impact of various factors on the system performance.

A. Simulation Settings

For the moving trace of vehicles, we employ the open-source microscopic space-continuous time-discrete traffic simulator SUMO to generate the movements of vehicle nodes. Since there are few protocols to address the problem of downlink strategy of safety message dissemination, in this paper, we compare the performance of our scheme (CMDS) with CLBP and the common flooding scheme. Specifically, we assume that a source vehicle suffers from an accident and broadcasts a safety message surroundings. The bus which receives the message at the earliest time will upload the message to the cloud.



(a)

(b)

Fig. 7. Two scenarios for the simulation. (a) a road. (b) a grid-like map.

TABLE I
PARAMETERS SETTING OF VANET INTERFACE.

Parameters	Value
Physical/Mac protocols	IEEE802.11p
Transmission range	R=250m
CW Min/Max	31/1023
Data Rate	11Mb/s
Traffic simulator	SUMO
Safety message size	512bytes
Feedback message size	14bytes
Confirm message size	10bytes
Number of vehicles on road/map	100/600
Max vehicle speed	14m/s
Carrier frequency	2.4GHz
Transmission power	10mW
RSS Threshold	-89dBM
Bit rate	18Mbps
α_1	0.8
α_2	0.2
r_{max}	7

The dissemination delay is defined as interval from the time that the safety message is formulated by the source vehicle until the time that all vehicles receive it. We test the dissemination delay in different scenarios as shown in Fig. 7. In the Fig. 7(a), we deploy 100 vehicles on a 2-kilometers road. The source vehicle only needs to disseminate the safety

TABLE II
PARAMETERS SETTING OF LTE ADVANCED INTERFACE.

Parameters	Value
Physical/Mac protocols	LTE Advanced
Carrier frequency	2GHz
eNodeB Trans Power	15W
System Loss	1dB
Packet size	512bytes
Uplink channel bit rate	10Mbps
downling channel bit rate	1000Mbps

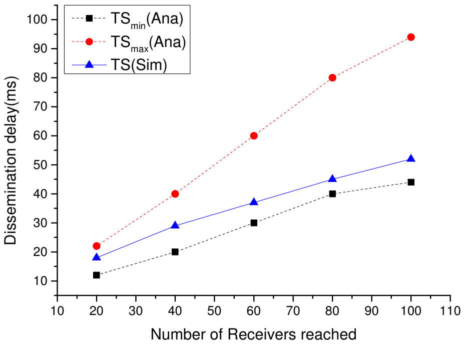


Fig. 8. Comparing with analytical results.

message to the other vehicles on this road. We deploy 600 vehicles on a grid-like map as shown in the Fig. 7(b). The proportion of buses varies from 2%-10%. All vehicles are equipped with IEEE802.11p device and buses we deployed can connect to cloud through their LTE interface card. Table I and Table II list the simulation parameters of VANET and LTE network, respectively.

The simulation includes three parts: (1) Comparing the simulation results with the analytical results.(2) Studying the dissemination delay under different proportion of buses. (3) Comparing the performance with other protocols in terms of dissemination delay and overhead.

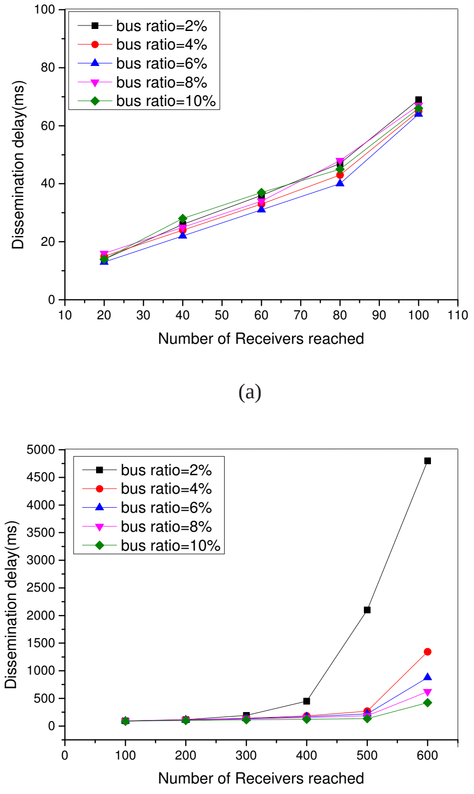
B. Validation of analytical results

We first verify the performance analysis of Sections IV on the safety message dissemination. We suppose that two buses are elected as the gateways which bracket a 2-kilometers road segment. We then investigate the message dissemination on this road segment.

Fig. 8 shows both simulation results and analytical results. We can observe that the simulation results fall into the range of the analytical results, which validates our mathematical analysis. Moreover, the message dissemination delay is much closer to analytical minimum value. This is because the elected gateways disseminate safety message simultaneously on both ends of the road segment.

C. Impact of bus distribution on message dissemination

In this part, we evaluate the impact of the the bus distribution on the effectiveness of our strategy. Fig. 9(a) shows the safety message dissemination to vehicles on a single road. we can see that the delays are quite similar with different bus distribution ratio. This is because uploading and downloading safety message from the cloud would cost longer time compared to the time for V2V communication in case of high intervehicle connectivity, and the dissemination process would stop earlier than the gateway obtains the safety message from the cloud. Therefore in this case, the main factor affecting the message dissemination is the quality of V2V communication.



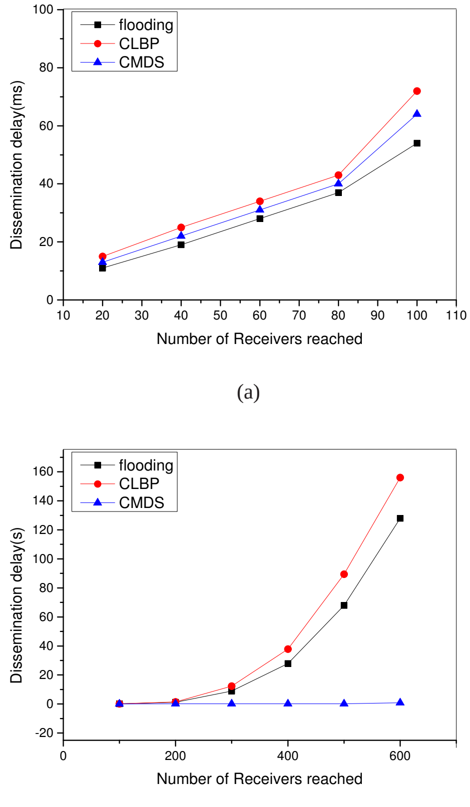
(a)

(b)

Fig. 9. Impact of bus distribution ratio on dissemination delay in different scenarios. (a) the road. (b) the grid-like map.

Fig. 9(b) shows a scenario in which vehicles runs on the grid-like map. We can see from the figure that the dissemination period is a time-consuming process when the bus distribution ratio is 2%. This is because the dissemination process will cost relatively long time on the roads where buses are sparsely distributed. When the bus distribution ratio is more than 6%, the dissemination delay decreases significantly and is less than 1s. When the bus distribution ratio reaches 10%, the gateways could be evenly distributed on the road by using the proposed gateway selection method. Almost all the vehicles can get the safety message from a gateway directly. In this case, the major influential factor of the message dissemination is the quality of LTE communication.

In Practice, the pre-arranged bus route and schedule may vary in different urban scenarios, which to some degree may have impact on the performance of our strategy. To facilitate the mathematical analysis and simulation, we assume that the buses on the road are subject to Poisson distribution. Nevertheless, through the comparison of the above two figures, we can readily see that the scale of targeted area has little impact on the effectiveness of our scheme, while increasing the bus distribution ratio is the most effective way to reduce delay.



(a)

(b)

Fig. 10. Comparing with other protocols in terms of dissemination delay in different scenarios. (a) the road. (b) the grid-like map.

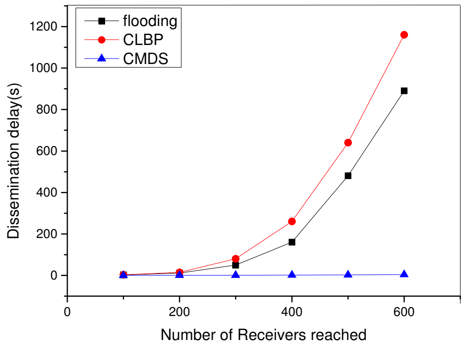


Fig. 11. Comparing with other protocols in terms of dissemination delay when considering the traffic lights and buildings influence.

D. *Comparing with other protocols*

We now compare the performance in terms of the dissemination delay and overhead among the three protocols. The overhead is the number of safety messages needed to be sent by vehicles to reach all receivers. The bus distribution ratio is set to 6%. As shown in Fig. 10(a), we can see that our scheme shows the similar performance with CLBP and the flooding scheme in case of a single road. However, the result will be quite different for grid-like scenarios, as shown in Fig. 10(b). The dissemination delay of our scheme is much lower than the other two schemes.

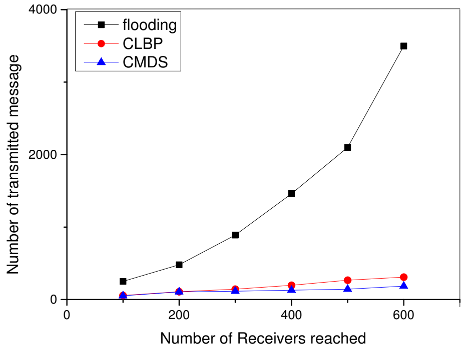


Fig. 12. Comparing with other protocols in terms of overhead.

To investigate the impact of traffic lights and buildings on the system performance, we deploy traffic lights at all intersections and buildings on road side, where the time interval between traffic light changes is set to 30 seconds, and all vehicles are assumed to communicate with each other on one-dimensional road due to the severe signal attenuation caused by buildings. We can see from Fig. 11 that the performance difference among three schemes is more significant. Meanwhile, the traffic lights and buildings have a little influence on the performance of our scheme.

Fig. 12 shows the communication overhead of the three schemes. We can see that the overhead of our scheme and CLBP is much lower than flooding. In our proposed scheme, vehicles could always acquire safety message from the gateway directly in the scenario with normal gateway density, so the overhead of our scheme is relative lower than that of CLBP. The comparison shows our scheme is effective in disseminating safety messages to a wide range of targeted area, with both low dissemination delay and overhead.

VI. CONCLUSIONS

In this paper, we have proposed a cloud-assisted downlink safety message dissemination framework to effectively disseminate traffic information by exploiting the advantages of both wireless networking and cloud computing technologies. In our framework, the cloud collects massive traffic flow information and selects a set of gateways, which are buses equipped with both cellular and VANET interfaces. Once a gateway receives the message from the cellular network, it will further distribute the message to nearby vehicles by V2V communication. To minimize packet loss and redundancy caused by broadcasting, we have designed a parallel multi-point safety message dissemination approach. To evaluate the performance of the proposed scheme, we have mathematically analyzed the dissemination delay of our scheme, which is helpful to understand how the safety message is swiftly transmitted to the desired receivers. We also have verified the effectiveness of our scheme by extensive simulation experiments. These results show that the proposed scheme not only can disseminate messages efficiently and rapidly, but also can significantly reduce the cellular communication cost.

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