The Next Generation Vehicular Networks: A Content Centric Framework

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Abstract—Due to the expanding scale of vehicles and the new demands of multimedia services, current vehicular networks face the challenges to increase the capacity, support mobility and improve quality of experience (QoE). An innovative design of next generation vehicular networks based on the content centric architecture has been advocated recently. However, the details of the framework and related algorithms have not been sufficiently studied. In this article, we present a novel framework of content-centric vehicular network (CCVN). By introducing a content centric unit, contents exchanged between vehicles can be managed based on their naming information. Vehicles can send interests to obtain wanted contents instead of sending conventional information requests. Then, we present an integrated algorithm to deliver contents to vehicles with the help of content centric units. Contents can be stored according to their priorities determined by vehicle density and content popularity. Pending interests are updated based on the analysis of transmission ratio and network topology. The location of content centric unit to provide content during the moving of vehicles is determined by the forwarding information. Finally, simulation experiments are carried out to show the efficiency of the proposed framework. Results indicate that the proposed framework outperforms the existing method and is able to deliver contents more efficiently.

I. INTRODUCTION

With the rapid development of mobile communication and intelligent transportation technologies, vehicular networks have emerged as a new paradigm [1][2]. Vehicular networks can provide not only pleasant and safety driving but also various kinds of services such as multimedia entertainments and social interactions on the go [3][4]. In existing vehicular networks, vehicles are equipped with on board units (OBUs) so that they can communicate with each other by vehicle to vehicle (V2V) communications. Vehicles are also able to connect to roadside units (RSUs) by vehicle to infrastructure (V2I) communications. Nowadays, there are 10% of moving vehicles on the road that are wirelessly connected. It is reported that 90% of vehicles will be connected by 2020 [5]. To satisfy the new demands, the design of next generation vehicular networks becomes an important issue.

There are new challenges to design the next generation vehicular networks. First, with an ever-increasing scale of vehicular contents, network capacity becomes limited to efficiently deliver contents to vehicles. Secondly, vehicles may pass through different locations when contents are delivered, how to manage contents in different locations should be considered [6]. Thirdly, due to the high velocity of vehicles, quality of experience (QoE) of in vehicular networks should be improved to provide guaranteed services.

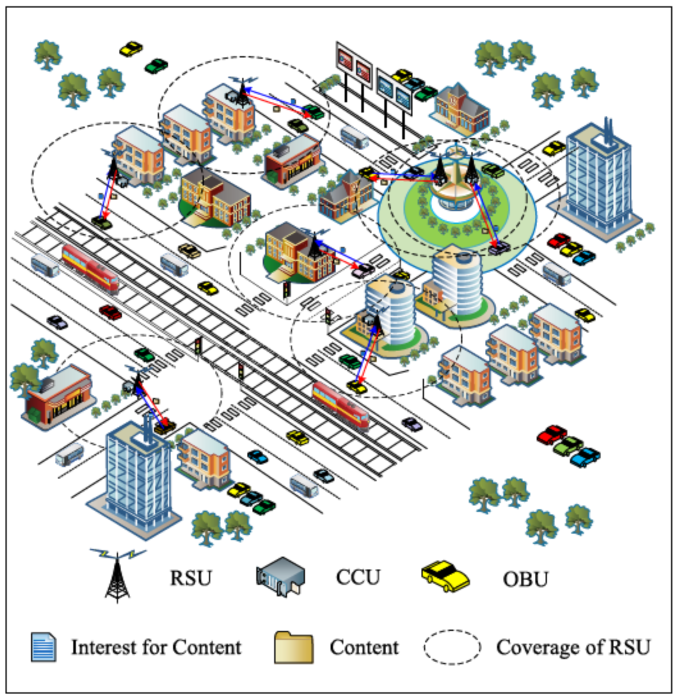

Fig. 1. Overview of the content centric vehicular network framework.

Recently, content centric networks [7][8] have been advocated to meet the above challenges to design the next generation vehicular networks. In a content centric vehicular network, the content consists of two types of packets, i.e., interest packets and content packets. An interest packet consists of the naming information of a content. A vehicle can request a content by sending an interest packet. The corresponding content packet will be sent to the vehicle if others have the replica of the content.

There are some advantages in designing the next generation vehicular networks based on content centric architecture, which are listed as follows. (1) Multiple content stores are distributed over the content-centric vehicular networks. These content stores keep the replicas of content and provide these replicas to moving vehicles if they have an interest of this content. In this way, network capacity can be increased by deploying content stores on the existing RSUs. (2) Contents are managed by their naming information in content-centric vehicular networks. When the replicas of the original content spread among different locations, due to the mobility of vehicles, the overhead of updating can be decreased because these replicas are considered the same content as they have the same naming information. (3) Unlike existing methods, content-centric vehicular networks can deliver contents based on their pending time and forwarding information, so the QoE factor is considered in designing the content-centric vehicular network architecture.

Although the content-centric vehicular network architecture is believed to be efficient, the detailed framework has not been studied. In addition, the associated algorithms of efficiently determining content storage, managing pending interests, and controlling forwarding information, have not been resolved.

In this article, we present a novel framework for content centric vehicular network (CCVN), as shown in Fig.1. We first introduce a content centric unit (CCU) to work with the conventional OBUs and RSUs. A group of CCUs can be distributed in the network to store the replicas of vehicular contents. Contents are managed by their naming information, where vehicles can request contents based on their interests. Each CCU has a content store to keep contents, a pending interest table (PIT) to manage interests, and an forwarding information base (FIB) to control information routing. Next, we propose a novel algorithm for efficiently delivering contents with CCUs. We define the storage priority of contents based on vehicle density and content popularity. The content store can be efficiently used by the replacement of content with the proposed priority. The pending interests in PIT are updated based on the transmission ratio and network topology. We select the location to provide content to vehicles based on the analysis of forwarding information in FIB. Finally, the simulation experiments are carried out to evaluate the proposed framework.

II. Next Generation Vehicular Networks

A. Vehicular Networks

In vehicular networks, V2V communication mainly relies on the collaborations among vehicles. Due to vehicle mobility and channel capacity, the performance of V2V is too limited to provide vehicles with reliable services. To resolve this problem, V2I is introduced by deploying roadside infrastructures along roads. V2I communication can help vehicles to download or upload contents.

When a vehicle enters the coverage of an RSU, it can send a request for content. The RSU fetches the requested content from a content server and provides the vehicle the content using existing networks. After obtaining the content from the RSU, the vehicle can share the content with other vehicles on the go.

Delivering contents timely from roadside infrastructures to vehicles becomes important to provide moving vehicles with a satisfied service. A plausible approach is that roadside infrastructures store partial contents in advance in a buffer. If the requested content is in the buffer, the road infrastructure sends the content to the vehicle directly via V2I communication. By doing so, both transmission delay and cost can be decreased.

B. New Trend of the Next Generation Vehicular Networks

Recently, there are some new trends in designing the next generation vehicular technologies, e.g, through device to device (D2D) communication and heterogeneous vehicular networks.

With an ever-increasing scale of intelligent transportations and content requests, massive contents generated by vehicles lead to a heavy network load and overhead. With D2D communications, vehicles can send and receive contents directly from others, instead of connecting to base station or RSUs [9]. With D2D, content delivery is provided in short range yet with high rate. Especially, in a congested area, vehicles can construct an ad hoc network and share contents with others directly to decrease traffic load and transmission cost.

Another approach to efficient content delivery is to design a heterogeneous vehicular network with small cells and macro cells [10]. Considering the distribution of vehicular contents, the small cell technology can provide access points for the vehicles within the coverage of RSUs. Different RSUs can communicate with each other by macro cells. With the cooperation between macro cells and small cells in a heterogeneous vehicular network, the network load can be decreased.

C. Challenges of Next Generation Vehicular Networks

Although there are new trends in designing the next generation vehicular networks, the research challenges come as follows.

Capacity Increase

Due to the high cost of deploying roadside infrastructures and their limited capacity of storage, it is impossible to store all contents on roadside infrastructures in vehicular networks [11]. Contents in vehicular networks have several unique characteristics [12][13]. For example, some content may be popular and frequently requested by vehicles. Roadside infrastructures need to selectively cache contents to make good use of their buffers. In addition, adjacent roadside infrastructures can cooperate with each other to store contents. Therefore, how to store contents in buffers to increase the capacity of vehicular networks becomes a new issue.

Mobility Support

Because of the mobility of vehicles, a group of content replicas of the original content may be kept in different vehicles and roadside infrastructures. However, as the current vehicular networks recognize these replicas as different contents, it causes huge overhead to manage these replicas, resulting in a low efficiency of content storage and delivery. Instead of focusing on where a content is from, the next generation vehicular networks should care about what the content is. Thus, how to support mobility in vehicular networks becomes a challenging issue.

QoE Improvement

The velocity of vehicles is higher than other mobile devices. The sojourn time of moving vehicles in the coverage of roadside infrastructures is short. Delivery of contents may not be finished during the period when the vehicles are within the transmission coverage. As a result, the networking QoS may degrade significantly in the case of a high velocity. Therefore, in the next generation vehicular networks, how to improve vehicles' QoS is a non-trivial issue.

III. Content Centric Vehicular Networks

Content centric networks have been advocated to meet the above challenges. Content consists of two types of packets: content packet and interest packet. An interest packet contains the naming information of a content such as content ID. When a vehicle needs a content, it sends an interest packet. Then, if another vehicle or RSU has the replica of this content, the content will be sent to the requesting vehicle. The above challenges can be met because of the following reasons.

Capacity Increase

In the content centric vehicular networks, a content is cached in a group of content stores which are placed along the roadside. These content stores can keep the replicas of popular contents which vehicles may request. As content stores are available on both vehicles and RSUs, the network capacity can be increased.

Mobility Support

A content is recognized by its naming information which is requested in an interest packet. When different vehicles or RSUs keep the same replicas of a content, the vehicular networks can recognize that these replicas are from the same content. When the original content is updated, the vehicular networks can update the replicas at different locations. Therefore, the network overhead can be decreased in supportting the mobility of vehicles.

QoE Improvement

Unlike the traditional caching methods, the content store in the content centric vehicular networks leverages the pending interest table and forwarding information base to improve QoE. A pending interest table shows the waiting time to obtain the content, and the forwarding information base keeps the routing information of the content. A content store can selectively cache the content based on the pending time and routing information, with the consideration of the QoE.

IV. Framework of Content Centric Vehicular Networks

In this article, we propose a novel framework for CCVN. As shown in Fig.2, the framework consists of on board units, roadside units and content centric units.

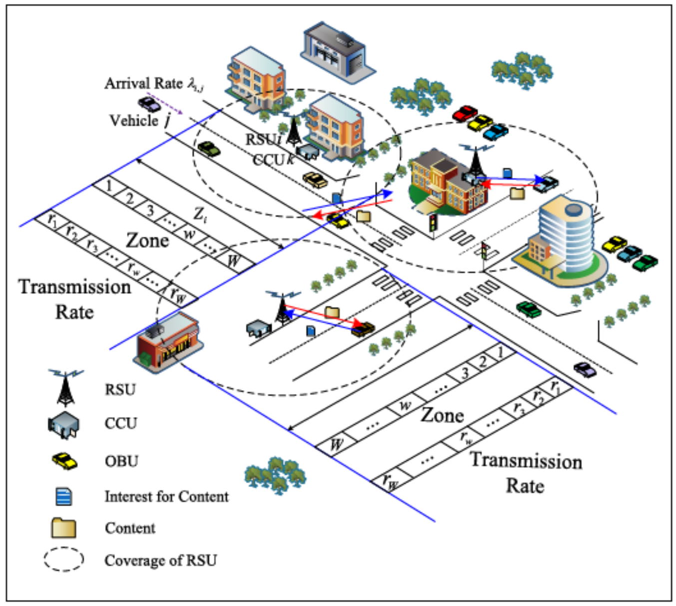

Fig. 2. Illustration of the content centric vehicular network architecture.

A. Network Architecture

On Board Units

The OBUs are moving vehicles that have on-board communication capacities. Each OBU has a limited caching capability to support multimedia infotainment applications. Different OBUs can communicate with each other, where vehicular contents can be shared and exchanged among vehicles. Within the coverage of RSU i, the arrival rate of a given vehicle j (j= 1,…,J) is denoted as $\lambda_{i,j}$.

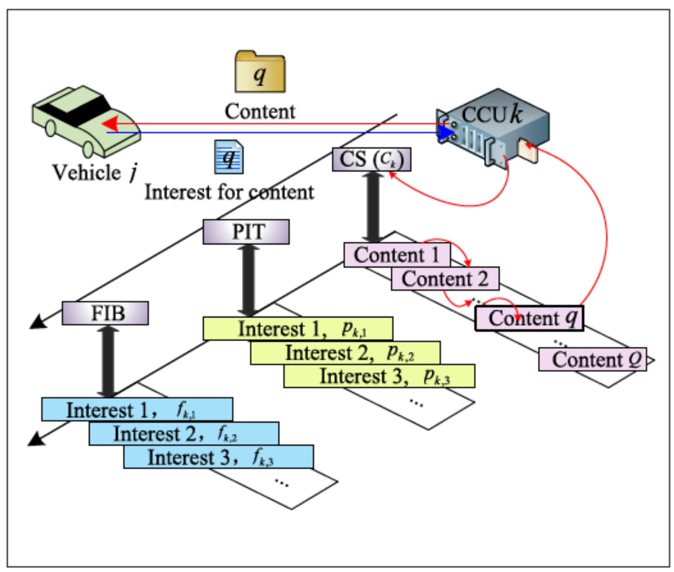

Fig. 3 (a). Status of a CCU when a content is available.

Roadside Unit

A group of RSUs are placed along the road in a distributed manner. Each RSU can provide vehicles with wireless connections when vehicles pass through its coverage area. Different RSU i (i= 1,…,I) has different coverage area z_i. When a vehicle communicates to RSU i, the coverage area of

z_i can be divided into zones w (w= 1,…,W). As the distance between the vehicle and the RSU changes when the vehicle is moving, the transmission rate in each zone w varies and is defined as r_w.

When original contents change, the corresponding replicas on RSU(s) are updated at first. Then, when a vehicle needs to update the replicas, it will retrieve the updated copy from nearby RSU(s) that has the updated replicas. For example, in an intelligent transportation system (ITS), the traffic information of a particular street might be updated every 5 minutes. If a vehicle is approaching to this street and has a replica of the street's traffic information that was collected 5 minutes ago, it will update this replica. After the vehicle receives the updated content, it can spread it to other vehicles that need to update the replicas as well.

Content Centric Unit

CCUs are deployed to facilitate content dissemination to vehicles. Each CCU k (k= 1,…,K) is a communication gateway to vehicles with an embedded content store c_k. In Fig.3 (a), when a vehicle sends an interest for content q (q= 1,…,Q), if the replica of content q is stored in content store c_k, it will be provided to the vehicle. In each CCU, there is a pending interest table to keep the list of contents that are requested by vehicles. There may be some contents that are unavailable in the content store of a CCU, due to its limited storage capacity. In Fig.3 (b), content q is requested by a vehicle and content store c_k does not have the replica. The CCU keeps a pending interest of content q which consists of the naming information of the content and the pending time $p_{k,q}$. CCU k has a forwarding information base $f_{k,q}$ to keep the routing information which contains the replica of content q.

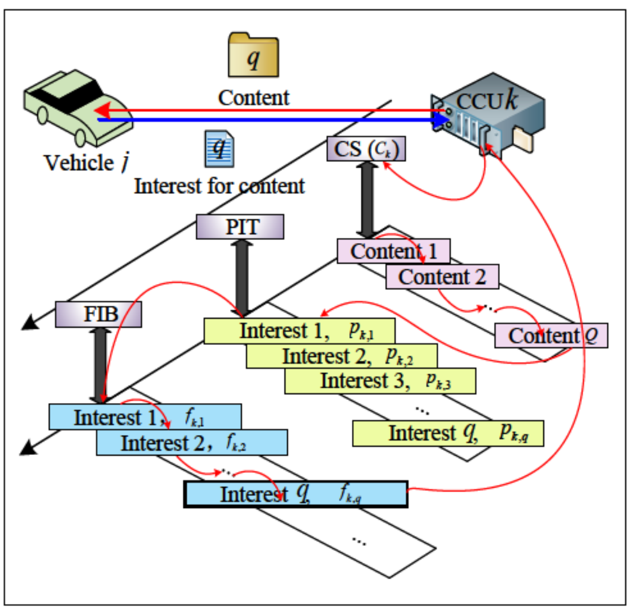

Fig. 3 (b). Status of CCU when a content is unavailable.

The forwarding information base keeps the information needed to achieve routings among vehicles and/or RSUs. A group of RSUs can be connected via the backbone network and work cooperatively to share one CCU. The shared CCU will be responsible for providing content stores, keeping pending interests, and updating forwarding information for this group of RSUs within its serving area.

B. Framework of CCVN

Unlike the conventional methods, the content requesters in a vehicular network are vehicles with a high mobility. On one hand, vehicles cannot wait for a long pending time as in the traditional content centric networks. As a result, the efficiency in pending interest table in vehicular network must be improved. On the other hand, a single RSU may not be able to provide the whole content to a shortly connected vehicle. The vehicle may need to pass through the coverage areas of several RSUs by contacting multiple CCUs.

Our work presents a novel framework of CCVN, which is different from existing ones [14][15]. Firstly, by introducing a content centric unit, vehicles can exchange contents based on their naming information. Instead of sending the conventional information requests, the vehicles send interests to obtain wanted contents. Secondly, an integrated algorithm is proposed to deliver contents to vehicles with content store, pending interest table, and forwarding information base in the content centric units.

Content Storage in CCVN

As the content store in a CCU has a limited storage capacity, how to determine the priority of vehicular contents becomes important. With the arrival rate $\lambda_{k,j}$ of a moving vehicle j, the arrival rate of vehicles in the coverage of CCU k becomes $\lambda_k = \Sigma_j(\lambda_{k,j})$. As the request of contents follows a Zipf distribution, the probability that a request from vehicles is for content q can be computed by α / e_q^{β}. α and β are the Zipf parameters and e_q is the ranking of content q, based on the request time. Here, parameter e_q is used to reflect the popularity of content, which can take the distribution of content popularity into consideration to improve the performance. The priority of this content in the content store of CCU can be determined by $\Sigma_j(\lambda_{k,j})\cdot \alpha / e_q^{\beta}$. As shown in Fig.4.(a), when a content store is full and needs room for new contents, the stored content with the lowest priority (arg min $(\Sigma_j(\lambda_{k,j})\cdot \alpha / e_q^{\beta}.)$) will be removed from the content store of the CCU.

Pending Interest in CCVN

If a requested content q is available in the content store of CCU k, it will be provided to the vehicle that sends the request. Otherwise, CCU k will consider the request in the pending state and keep it in its pending interest table with a pending time $p_{k,q}$. As shown in Fig.4.(b), if $\varepsilon_{k,j} < \Sigma_w (\tau_{q,w} / r_w) + p_{k,q}$, the content q will be delivered to the vehicle when it is within the coverage area of CCU k. $\tau_{q,w}$ denotes the data size of content q that is transmitted in the w-th zone. $\varepsilon_{k,j}$ denotes the time that vehicle j stays in the coverage of CCU k. Here, a CCU can serve one or multiple RSUs. There can also be multiple CCUs in one RSU.

When a vehicle leaves the current RSU and moves to the next RSU (if the connected CCU is different), its pending interest will be transmitted to the next CCU during its moving. Therefore, the pending interest information can be shared among different CCUs, which works in a cooperative way among RSUs to handle the cases where the vehicle moves to another place located within another RSU.

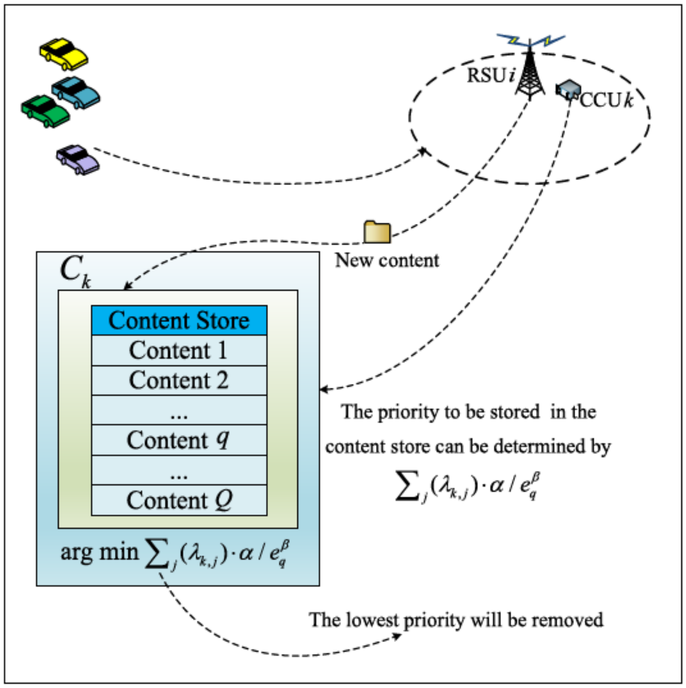

Fig. 4 (a). Content selection in a content store.

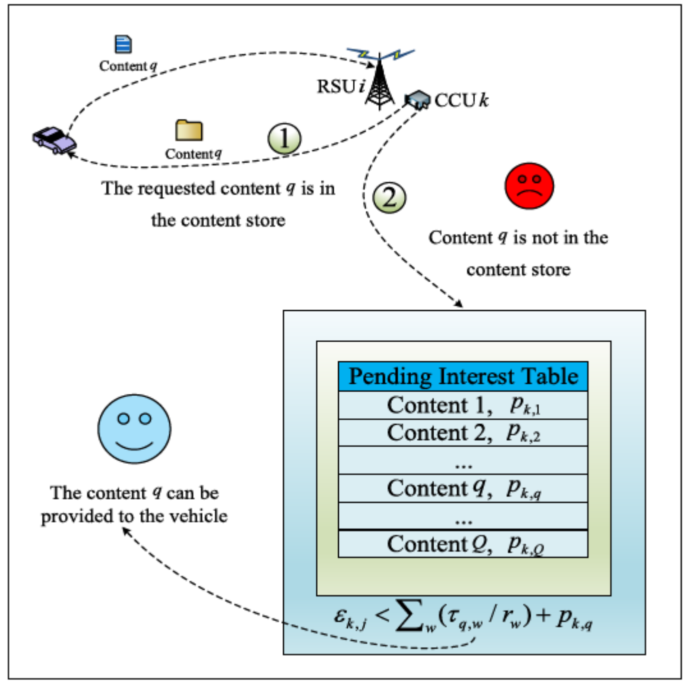

Fig. 4 (b). Procedure of updating a pending interest table.

Forwarding Information in CCVN

Due to the large amount of contents and short period of contact time between vehicles and RSUs, a vehicle may not be able to obtain the entire set of contents by just downloading them from a single RSU. If the vehicle estimates this situation is occurring, it will send the path that it will pass through nearby RSUs, in order to request for connections in advance. Then an optimal list of CCUs is provided to the vehicle which will pass by. Because the vehicle only provides short-distance path, instead of the path of its whole journey, the CCUs do not know the complete route of the vehicle, so that location privacy of this vehicle can be protected.

In Fig.5, if content q cannot be delivered when this vehicle is within the coverage area of CCU k, CCU k will check its forwarding information base. The forwarding information base provides a list of CCUs that the vehicle will pass in the near future. For each CCU l $(l= 1,\dots,L)(L<K)$ in the list, if there is a replica of content q, we set $f_{l,q}$=1. Otherwise, we set $f_{l,q}$=0. Among these CCUs, if $f_{r,q}$=1 and r =arg min $(d_{l,k})$, CCU r will be selected to deliver content q to the vehicle when it passes this CCU. Here, $d_{l,k}$ means the distance between CCU l and CCU k.

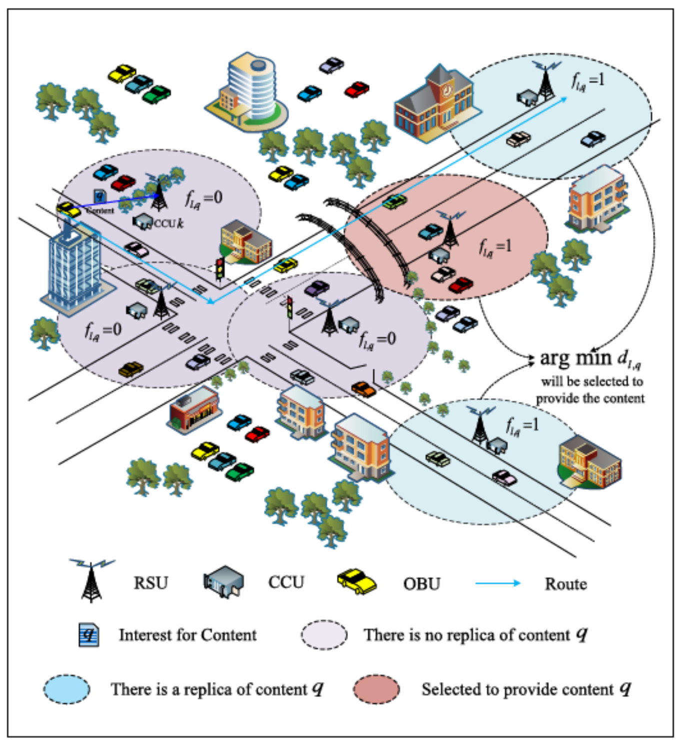

Fig. 5. Selection of a CCU to deliver content based on forwarding information.

C. *Performance Evaluation*

We evaluate the hit rate and delay of content store by comparing the proposed CCVN with the conventional scheme. In the conventional scheme, contents are stored based on request times in the whole vehicular networks without considering the different popularity in the coverage area of different CCUs. Besides, the content is delivered to the vehicle without the selective CCUs suggested by the forwarding information. In simulations, the total number of contents in the vehicular networks is 100. The popularity of contents follows the Zipf distribution. The parameters of Zipf distribution is set to be 0.85. The maximum number of contents stored in a RSU is 10. The arrival rate of vehicles entering an RSU is determined by the Poisson distribution. The maximum values of and vehicle density and velocity are 110Veh/Km and 100Km/h, respectively. The simulation time changes from 100s to 500s. The content size is uniformly distributed from 0.125M to 0.25M bytes. The network bandwidth to fetch content from a CCU is 3M bps while the bandwidth to fetch content from the original content server is 1.5 M bps.

From the result shown in Fig. 6 (a), it can be seen that the proposed solution can obtain a higher hit rate than existing scheme with different vehicle density ρ. Furthermore, with the result in Fig. 6 (b), it proves that the proposed solution outperforms the conventional scheme with a low delay when the simulation time changes.

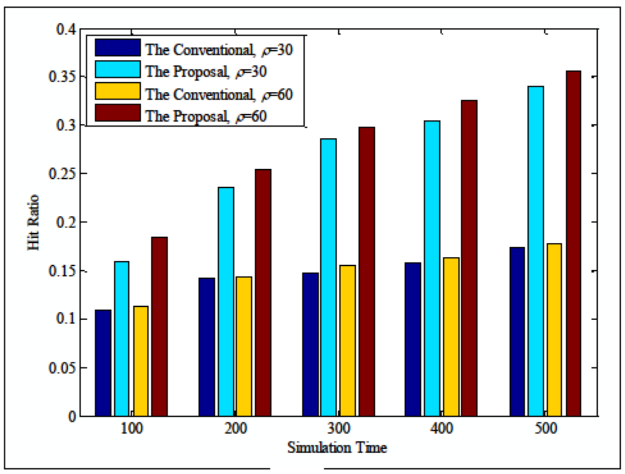

Fig. 6 (a). Hit rates given different simulation time.

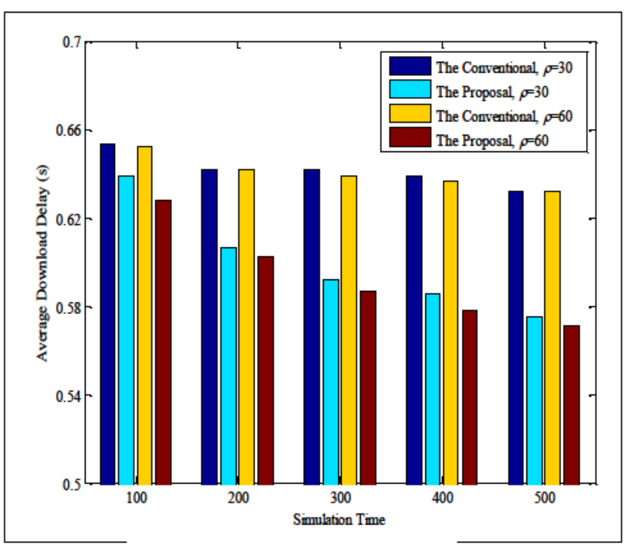

Fig. 6 (b). Average downloading delay given different simulation time.

V. Summary and Future work

In the article, we present a novel framework of the next generation vehicular networks based on the content centric architecture. We design a content centric unit in the network to deliver vehicular contents from OBUs and RSUs. Vehicles can request contents based on their interests and the contents are managed by their naming information. We propose an integrated algorithm to cache contents in content stores, keep pending interests, and update forwarding information. The proposed framework can increase network capacity, support vehicle mobility, and improve QoE. Simulation results verify the efficiency of the proposed work with comparisons to the conventional scheme. Some future research topics are listed as follows.

- Cloud Based Vehicular Networks

As the scale of vehicular networks rapidly increases, more and more vehicles will be connected to each other in the future. Vehicles may produce a huge amount of contents and request various types of services. A cloud based vehicular network will be essential to process and optimize vehicular contents with the cloud-aided resources.

- Social Aware Vehicular Networks

Similar to mobile social users who use mobile devices to access mobile social networks, vehicles can also form a vehicular social network. Vehicles that have the same interest may exchange contents, e.g., traffic status and road conditions, to each other. A major research issue in such a network is to understand the social relations between vehicles, which could be quite different from other types of social networks.

- Privacy and Security Aware Vehicular Networks

Because vehicles are connected through RSUs or CCUs via wireless communications, it is extremely important to provide a secure connection for them. At the same time, as vehicles may exchange or share contents with others, the privacy of vehicles must be protected.

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