Consistency Control to Manage Dynamic Contents over Vehicular Communication Networks

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***Abstract*— To improve driving comfort and provide entertainment services, vehicular communication networks (VCNs) have appeared as an emerging solution, which consists of road-side units (RSUs) and on-board units (OBUs) to distribute multimedia contents. However, as most of OBUs always request the stored contents in the RSUs, how to update the contents in these RSUs when the original changes at its original servers has become an important issue to be dealt with. This paper proposes a novel method to resolve the above problem. Firstly, based on the characteristics of peers and geographical information, we decide which replica of which content in RSUs should be updated when its original changes. Secondly, by comparing the delivery cost of wired and wireless transmission, we decide whether the updated content should be delivered from a fixed peer or other mobile peers. Lastly, the detailed algorithm is presented and summarized.**

***Index Terms*— Vehicular Communication Networks, Consistency Control, Contents Delivery**

I. INTRODUCTION

Vehicular communication networks (VCNs) has become one of the promising solutions to distribute multimedia contents services to drivers. With the development of broadband technologies, the VCNs can provide convenient and diverse multimedia contents during the time of both inter-vehicle communications and roadside-to-vehicle communications.

In the VCNs, road-side units (RSUs) and on-board units (OBUs) are used to deliver the vehicular contents. On the one hand, RSUs are a group of fixed peers connected by wired networks. These fixed peers are placed along the roadside. On the other hand, OBUs are moving peers which are moving along the road. By using both the OBUs and RSUs, all moving vehicles in the VCNs can connect each other by wireless networks and are also able to access the fixed peers within their coverage areas.

However, since OBUs have limited storage capacity and unstable connection compared with RSUs, it is necessary to store several replicas of the original content in a group of RSUs. If a moving vehicle accesses a nearby RSU and the requested content is available with the latest version, the requested content can be provided from the RSU to this vehicle immediately. Otherwise, the RSU needs to contact OBUs (in its coverage area) or other RSUs (connected by wired network) to get the latest version of the requested content, which may result in an extra user delay. Therefore, in order to balance the tradeoff between update cost and user delay, suitably updating the replicas in RSUs, called consistency control, becomes critical for content delivery in vehicular networks [11]-[16].

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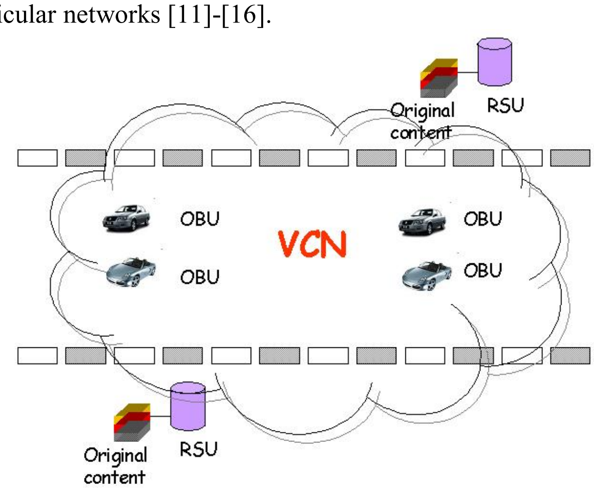

Figure 1: System Architecture of VCN

In this paper, the consistency control in vehicular networks is studied. At beginning, the theoretical analyses on connection time, and request status for peer and contents are carried out by considering the characteristics of vehicular networks. Then, a new control algorithm is proposed by introducing two priorities. One is to decide which replica in the RSUs should be selected for update. Another is to decide whether the latest version of the content should be sent from a fixed RSU or a moving OBU. Simulation results show that the proposed consistency control algorithm can improve the network performance in terms of user delay, updated and download traffic.

II. RELATED WORK

Authors in [5] proposed a new architecture by dividing peer-to-peer (P2P) networks into several network-aware clusters. A file discovery control was used to obtain up to date status of peers and documents, while the resource provider selection algorithm was introduced to select proper peers for file retrieval. In [6], the proposed seven degrees of separation (7DS) algorithm anticipated the status and needs of users, and then fulfilled them by searching for information among peers. Users who are not connected to the Internet can fetch contents from their neighbors. Although these two works showed the efficiency to deploy contents delivery networks in wireless networks, their applications in vehicular networks are unknown.

In [4], a swarming protocol with a gossip mechanism and a piece-selection strategy, called swarming protocol for ad-hoc wireless network (SPAWN) was used to propose a cooperative solution for content delivery and sharing in vehicular networks. In this work, each moving peer can communicate with fixed peers by RSUs and can search interested files by gossip messages. The work in [3] discussed how to search contents in vehicular P2P networks by constructing a system based on social cluster relations, and then searching the contents based on lifetime and bandwidth.

Cabernet in [7] showed a practical system to distribute data among moving vehicles using WiFi access points during driving. A collection of tools for establishing connections with wireless points and the corresponding transport protocol to handle high non-congestive loess rate were presented. [8] and [9] talked about an information sharing method for inter-vehicular networks, where the maximum spreading of information queries among vehicles can be achieved with the reduction of useless queries and duplicated replies. Although all of the above work talked about the applications related vehicular networks, consistency control has not been considered.

III. Theoretical Analysis

A. System Model

The notations used in the analysis are summarized in Table 1. Consider a vehicular network defined in [2], as shown in Fig. 2. The network has total I RSUs, r_i (i= 1,…, I), which are fixed peers connecting with each other by wired links. In the j-th (j= 1,…, J) road $l_{i,j}$, which is located in the coverage area of r_i, the k-th (k= 1,…, K) OBU (the moving peer) $o_{i,j,k}$ is communicating with other moving peers by wireless links. $v_{i,j,k}$ and $\theta_{i,j,k}$ denote the moving speed and direction of $o_{i,j,k}$.

Table1: Parameter Definition

r_i	i –th RSU (fixed peer)
$l_{i,j}$	j –th road in the coverage area of r_i
$o_{i,j,k}$	k –th OBU (moving peer) in road $l_{i,j}$
$w_{i,j}$	number of moving peers in road $l_{i,j}$
t_i	total request times within the i –th RSU
$z_{i,j}$	average length of moving peers in road $l_{i,j}$
$u_{i,j}$	number of lanes in road $l_{i,j}$
$\beta_{i,j}$	average distance between moving peers in road $l_{i,j}$
$c_{i,j}$	coverage length of r_{ij} in road $l_{i,j}$
$v_{i,j,k}$	moving speed of moving peer $o_{i,j,k}$
$\theta_{i,j,k}$	moving direction of moving peer $o_{i,j,k}$
$tr_{i,j,k}$	transmission range from r_i to $o_{i,j,k}$
$\lambda_{i,j,k}$	request rate of $o_{i,j,k}$
s_q	data size of the q -th content
e_q	request ranking of the q -th content
$d_{m,n}$	shortest distance (hop count) from peer m to peer n
$b_{m,n}$	average bandwidth (per hop) during the path from peer m to peer n
$g_{m,n}$	connection time between peer m and peer n

B. Analysis of Content Priority

1) Connection time

Assume r_i and $o_{i,j,k}$ locate at coordinates (x_{ri}, y_{ri})and ($x_{o_{i,j,k}}$, $y_{o_{i,j,k}}$) respectively. *Let* $tr_{i,j,k}$ denote the transmission distance from r_i to $o_{i,j,k}$. When an OBU requests a Web access, according to Ref [1], the connection time between r_i and its connected moving peer $o_{i,j,k}$ can be obtained as follows:

$$g_{r_i,o_{i,j,k}} = \frac{\sqrt{(a^2+c^2)\cdot tr_{i,j,k}^{\;2} - (ad-bc)^2} - (ab+cd)}{a^2+c^2} \quad (1)$$

where

$$a = -v_{i,j,k} \cdot \cos\theta_{i,j,k} \quad (2)$$

$$b = x_{o_{i,j,k}} - x_{r_i} \quad (3)$$

$$c = -v_{i,j,k} \cdot \sin\theta_{i,j,k} \quad (4)$$

$$d = y_{o_{i,j,k}} - y_{r_i} \quad (5)$$

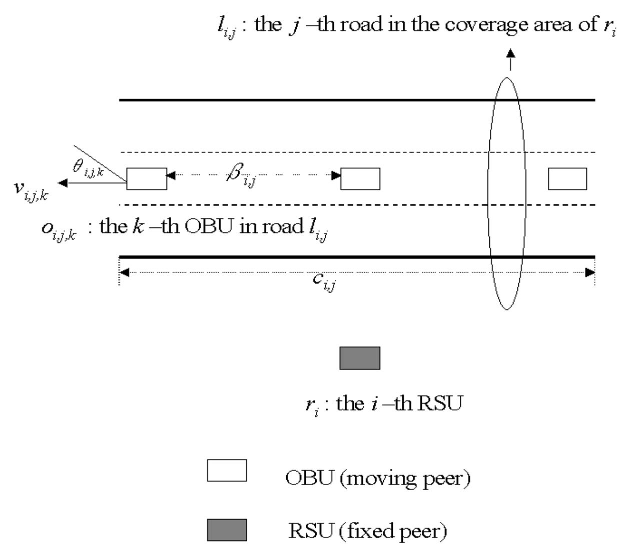

Figure 2: System Architecture

2) Probability of a request from a given mobile peer

As for the Web request with Poisson distribution, the probability that a request initiates from a given moving peer $o_{i,j,k}$ during its connection time can be obtained as

$$p_{i,j,k} = \frac{\lambda_{i,j,k}}{\sum_j \sum_k \lambda_{i,j,k}} \tag{6}$$

here $\lambda_{i,j,k}$ is the request rate of $o_{i,j,k}$.

3) Probability of a request for a given content

Since the content request of a Web access ordinarily follows Zipf distribution, the probability that the content q is requested can be obtained as

$$p'_q = \frac{\tau}{e_q^\sigma} \tag{7}$$

where τ , σ are parameters of the Zipf distribution, and e_q is the ranking of request times.

4) Request times for the given contents from the connecting moving peer

According to the previously derived probabilities, we can calculate the number of request times when a moving peer $o_{i,j,k}$ locates in the coverage area of r_i and requests the q-th content as

$$t_i \cdot p_{i,j,k} \cdot p'_q \tag{8}$$

where t_i is the total number of requests happened from all moving peers in all roads located in r_i 's coverage area within the past watching period Δt . t_i can be calculated as:

$$t_i = \frac{\Delta t \cdot w_i}{\sum_j \sum_k g_{o_{i,j,k}, r_i}} \tag{9}$$

where w_i is the total number of moving peers in all roads located in r_i 's area, and it can be obtained as

$$w_i = \sum_i w_{i,j} = \sum_i (u_{i,j} \cdot \frac{c_{i,j}}{(1+\beta_{i,j}) \cdot z_{i,j}}) \tag{10}$$

Let $u_{i,j}$ and $z_{i,j}$ be the number of lanes and the average length of moving peers in road $l_{i,j}$, respectively, and $c_{i,j}$ be the length of road $l_{i,j}$. The average distance between two moving peers, $\beta_{i,j}$, can be obtained by

$$\beta_{i,j} = \frac{\alpha_{i,j}}{\eta_{i,j}} \tag{11}$$

here, $\alpha_{i,j}$ and $\eta_{i,j}$ are the limited speed of the road and the expected traffic, respectively.

5) Content priority

We define the expected request times for the q-th content in the coverage area of RSU r_i as a content priority $cp_{i,q}$. By substituting (6), (7) and (9) into (8), $cp_{i,q}$ becomes

$$\begin{aligned} cp_{i,q} &= \sum_j \sum_k t_i \cdot p_{i,j,k} \cdot p'_q \\ &= \frac{\sum_j \sum_k (\lambda_{i,j,k} \cdot \Delta t \cdot w_i \cdot \tau)}{e_q^\sigma \cdot (\sum_j \sum_k g_{o_{i,j,k}, r_i}) \cdot (\sum_j \sum_k \lambda_{i,j,k})} \end{aligned} \tag{12}$$

C. Analysis of Peer Priority

Assume that there are M $(M<K)$ moving peers which have the updated version of the q-th content within the coverage area of r_i. For each moving peer $o_{i,j,m}$ (m= 1,..., M), let its shortest distance (hop count) away from the desired moving peer $o_{i,j,k}$ be $d_{o_{i,j,m}, o_{i,j,k}}$, and the average bandwidth (per hop) during the path from peer $o_{i,j,m}$ to peer $o_{i,j,k}$ be $b_{o_{i,j,m}, o_{i,j,k}}$.

When moving peer $o_{i,j,k}$ requests the content q and only the old version of content q is avaliable in RSU r_i, $o_{i,j,k}$ need to contact other peers to get the latest version of content q. We analyze the content request delay by considering the following two situations.

1) Delay to get contents from moving peers

In this case, the moving peer $o_{i,j,k}$ gets the latest version from other moving peer $o_{i,j,m}$. Thus, the delay to get content q becomes:

$$bt_{o_{i,j,m}, o_{i,j,k}} = \frac{s_q}{b_{o_{i,j,m}, o_{i,j,k}}} \cdot (d_{o_{i,j,m}, o_{i,j,k}} + |v_{i,j,m} - v_{i,j,k}| \cdot bt_{o_{i,j,m}, o_{i,j,k}}) \tag{13}$$

The above one can be further simplified as:

$$bt_{o_{i,j,m}, o_{i,j,k}} = \frac{s_q \cdot d_{o_{i,j,m}, o_{i,j,k}}}{(b_{o_{i,j,m}, o_{i,j,k}} - s_q \cdot |v_{i,j,m} - v_{i,j,k}|)} \tag{14}$$

2) Delay to get contents from fixed peers

In this situation, RSU r_i sends requests for the latest version of content q to other fixed peers r_n (n= 1,..., N, $n \in i$) which has the latest version of content q. And then, after getting the content from r_n, r_i sents it to the moving peer $o_{i,j,k}$. Thus, the total time to get content q becomes

$$bt_{r_i, r_n} + bt_{r_i, o_{i,j,k}} \tag{15}$$

where $bt_{r_i, r_n} = \frac{s_q}{b_{r_i, r_n}} \cdot d_{r_i, r_n}$ (16)

and $bt_{r_i, o_{i,j,k}} = \frac{s_q}{b_{r_i, o_{i,j,k}}} \cdot (d_{r_i, o_{i,j,k}} + v_{i,j,k} \cdot bt_{r_i, o_{i,j,k}})$ (17)

Then, the total time in this situation becomes

$$bt_{r_i, r_n} + bt_{r_i, o_{i,j,k}} = \frac{s_q}{b_{r_i, r_n}} \cdot d_{r_i, r_n} + \frac{s_q \cdot d_{r_i, o_{i,j,k}}}{(b_{r_i, o_{i,j,k}} - s_q \cdot v_{i,j,k})} \tag{18}$$

3) Peer Priority

we define a peer priority to take the the latest version of content q as $up_{i,j,k,q}$, where

$$up_{i,j,k,q} = \begin{cases} o'_{i,j,m} & (\min_m \{bt_{o_{i,j,m}, o_{i,j,k}}\} < \min_n \{bt_{r_i, r_n} + bt_{r_i, o_{i,j,k}}\}) \\ r'_n & (\min_m \{bt_{o_{i,j,m}, o_{i,j,k}}\} > \min_n \{bt_{r_i, r_n} + bt_{r_i, o_{i,j,k}}\}) \end{cases} \quad (19)$$

$O'_{i,j,m}$ denotes the moving peer which owns the minimum $bt_{o_{i,j,m}, o_{i,j,k}}$ when m changes, while r'_n denotes the fixed peer which owns the minimum ($bt_{r_i, r_n} + bt_{r_i, o_{i,j,k}}$) when n changes.

IV. PROPOSED ALGORITHM

A. Algorithm

Based on the defined priorities, the proposed algorithm follows the following two steps.

Step1: when the replica of the q-th content stored in RSU r_i is out of date, $cp_{i,q}$ will be calculated by using (12). If its value is beyond a determined threshold, this replica will be selected for update. Otherwise, it will not be updated until the next request comes.

Step2: after the replica of the q -th content stored in RSU r_i is selected for update by Step1, $up_{i,j,k,q}$ will be calculated (19). If $up_{i,j,k,q}$ is equal to $O'_{i,j,m}$, the data will be retrieved from the moving peer which owns the lowest $bt_{o_{i,j,m}, o_{i,j,k}}$. Otherwise, the data will be fetched from the fixed peer with the lowest ($bt_{r_i, r_n} + bt_{r_i, o_{i,j,k}}$).

B. Computational Complexity and Related Parameters

As the scale of VCN is being expanded, the computation complexity becomes huge if we need to calculate priorities of all replicas and all road-side and on-board units. Fortunately, previous work [19] showed that the distribution of Web access follows a Zip distribution, where most of requests always come for just a small set of replicas, for example, 10%. Besides, it also proves that 80% of the requests are served by only the top 4% of the most popular units. Based on the above analysis, we can only calculate a part of contents and units, resulting in a guaranteed performance, where the computation complexity can be reduced at the same time.

All of the parameters such as road distance and average car speed in (12) to calculate the content priority, can be obtained from the map information provided by the GPS navigation and others. For the parameters to calculate priority in (19), the number of hops can be got from the topology. The bandwidth can be also obtained by some existing methods including *Pathchar*, *SloPS* etc, where the accuracy can be guaranteed.

V. SIMULATION RESULTS

In this section, a simulation is carried out by using the real traffic data provided by the SUMO [10]. The topology of RSUs is decided by the Power-Law distribution [17]. For each connection, the bandwidth is decided by Bounded Pareto Distribution with a shape number 1.5 [18]. Each request from the OBU is directed to the nearest RSU.

There are 1000 Web contents to be distributed in the VCN. The access probability of each content is decided by the Zipf distribution [19] with a Zipf parameter 0.8. The size of data is selected at random.

For comparison purpose, five replication algorithms are considered. They are

1.Propagation
2.Invalidation
3.RSU-Based Update (RBP)
4. Content-Based Update (CBP)
5.Proposal

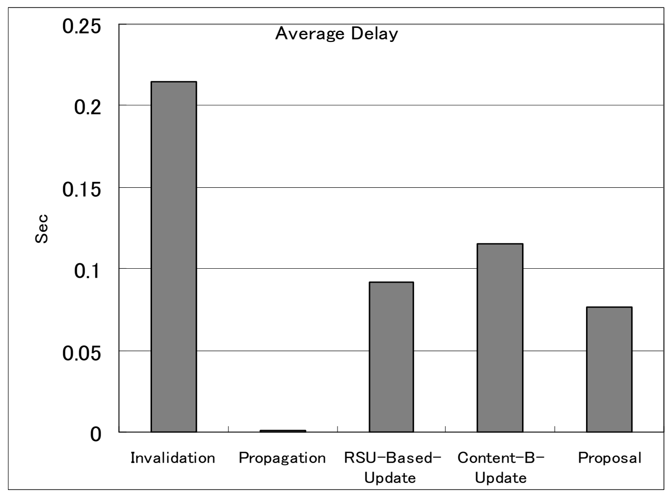

Figure 3: Average User Delay

Figure 3 shows the average user delay, which is defined as the time to get the latest version of data after the request. Because the updated version of the requested content is delivered to all replicas when a change is made at its origin server in the *Propagation*, its average delay is almost zero. However, if we study the network traffic caused by updating contents as shown in Fig. 4, it can be found that the network traffic caused by the *Propagation* is extremely huge, since each replica is selected for updating when its origin changes. On the other hand, in *Invalidation* the network traffic caused by updating content is zero as only an invalidation message is send, but its delay is the worst because the user needs to wait for the latest version of data to be fetched from the original server. Thus, both the *Propagation* and *Invalidation* are not acceptable for practical applications because of their bad balance between the delay and update traffic.

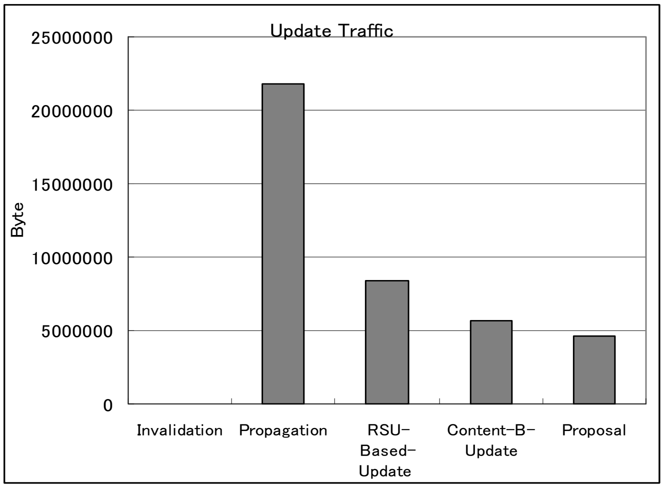

Figure 4: Traffic Caused by Content Update

All other three algorithms, including the proposed one, can achieve reasonable level of balance. Among these three algorithms (Proposal, RSU-Based Update and Content-Based Update), we can find that our proposal can get the best performance, where both of the lowest average delay and the lowest network traffic are obtained.

VI. CONCLUSION

In this paper, a novel algorithm for consistency control is proposed for vehicular networks to provide multimedia services. A content priority is proposed to decide whether a replica in the RSU should be updated, and a peer priority is proposed to decide whether the latest version of the requested data should be fetched from a fixed RSU or a moving OBU. Simulation results clearly demonstrate the performance improvement from the proposed algorithm.

As for the further work, more theoretical analysis and simulation experiment will be carried out.

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