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Article

CCN-Based Inter-Vehicle Communication for Efficient Collection of Road and Traffic Information

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Abstract: Recently, inter-vehicle communication, which helps to avoid collision accidents (by driving safety support system) and facilitate self-driving (by dissemination of road and traffic information), has attracted much attention. In this paper, in order to efficiently collect road / traffic information in the request / response manner, first a basic method, Content-centric network (CCN) for Vehicular network (CV), is proposed, which applies CCN cache function to inter-vehicle communication. Content naming and routing, which take vehicle mobility into account, are investigated. On this basis, the CV method is extended (named as ECV) to avoid the cache miss problem caused by vehicle movement, and is further enhanced (named as ECV+) to more efficiently exploit cache buffer in vehicles, caching content according to a probability decided by channel usage rate. Extensive evaluations on network simulator Scenargie, with realistic open street map, confirm that the CV method and its extensions (ECV, ECV+) effectively reduce the average number of hops of data packets (by up to 47%, 63%, 83% respectively) and greatly improve the content acquisition success rate (by up to 356%, 444%, 689%, respectively), compared to the method without cache mechanism.

Keywords: Inter-vehicle communication; content-centric network; cache miss

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1. INTRODUCTION

Inter-vehicle communication (IVC) is an important method to driving safety support system, via which vehicles exchange position and speed information to prevent collision accidents. This technique has been put into practical use in Japan since 2015, and still draws much research attention in the world [1][2][3][4].

Various types of information are handled by IVC, and can be roughly classified into two categories. One category is safety-related information (e.g., sudden brake of vehicles, emergency vehicle approach). Such information must be delivered to all vehicles fast and reliably, and failing to do so may lead to traffic accidents. For this reason, dissemination via broadcast in the push manner is effective for this category, which is characterized in that information is disseminated without explicit request [1]. The other category is driving comfort-related information (e.g., road closure, and congestion at forward intersections). Such information is not directly related to traffic accidents, and a delay in dissemination is allowed. In addition, vehicles with different routes usually have different interest. Therefore, dissemination via request/reply in the pull manner is often used for this category, which is characterized by the explicit request. This paper focuses on the 2nd category. However, as the number of vehicles requesting information increases, congestion due to repeated transmission of the same information becomes a problem.

In order to solve this problem, this paper suggests applying content-centric network (CCN [5]) for the efficient dissemination of road/traffic information in IVC [6]. CCN, often used for content dissemination in the Internet, has some points in common with the pull type dissemination in IVC. Content caching function of CCN is expected to prevent redundant dissemination and reduce the number of forwarding of data packets in IVC. However, there are also significant differences between IVC and CCN, as follows. (1) CCN usually assumes that the content is static and remains unchanged after creation, but in IVC, the content (traffic event) changes dynamically because the traffic and road conditions change continuously [7]. Therefore, conventional cache management policy in CCN cannot be directly applied in IVC. (2) CCN is designed for content dissemination on the Internet, where content provider and routers almost do not move. In comparison, vehicles move at fast speeds in IVC. In addition, it is necessary to devise a unique name for information exchanged by IVC. For example, when a certain traffic jam is detected by multiple vehicles and assigned different names, other vehicles may think multiple traffic jams exist. In summary, in order to apply CCN for efficiently disseminating (Pull type) road / traffic information in IVC, the following issues must be taken into account.

1) Problem 1: Content naming. How to name traffic events uniquely (and in a way easy to understand) when it is possible for multiple vehicles to detect the same traffic event?

2) Problem 2: Routing Interest / Data packets. Network topology is assumed to be almost unchanged in CCN, but in IVC it changes constantly because content requester, provider, and relay vehicles always move. So efficient routing is a challenge.

3) Problem 3: Content cache management. How to manage cache efficiently when content changes frequently and vehicles move?

In this paper, we first propose a basic method, CCN for vehicular network (CV). For Problem 1, a unique name is given for a traffic event by using intersections and the type of content, and for Problem 2, location based routing is adopted, and a relay vehicle is selected according to the progress made by each vehicle. As described in Problem 3, with location-based routing, it is preferred that the farthest vehicle be selected as the relay in order to reduce the number of hops. However, if the farthest vehicle does not have specified content in the cache buffer, while other nearer vehicles do have, the cache miss problem occurs. In addition, it is inefficient for all vehicles to cache the same content. Therefore, the basic CV method is further extended to address the cache miss problem (the ECV method) and cache content according to a probability decided by channel usage rate (the ECV+ method). Simulation evaluations on network simulator Scenargie, with realistic open street map, confirm that the proposed methods significantly reduce the number of hops (number of content transmission) and improve content acquisition success rate, and ECV+ achieves the best performance. The basic method was already presented at APCC [8]. In this paper, a new cache management policy is introduced to cache more contents to better exploit the storage in vehicles, and more evaluations (e.g., the impact of cache buffer capacity, vehicle density) are added to evaluate the effectiveness of the proposed method in different scenarios.

The rest of this paper is organized as follows: Section II reviews background and related works on CCN. Section III proposes the basic method for applying CCN to IVC, analyzes the problem of cache miss, and makes extensions from different aspects. Then, Section IV presents the evaluation results. Finally, Section V concludes this paper and points out future work.

2. RELATED WORKS

This section reviews related research on CCN and routing.

2.1 CCN

CCN is a network architecture that enables efficient content delivery [5]. When requesting a content, the requester issues an Interest packet specifying the content name instead of the content provider's address, and sends it towards the content provider. The requested content is sent back in the Data packet (response) from the provider and cached in the intermediate relay nodes. The cache is used later when the same content is requested again by other vehicles, and in this way the dissemination efficiency is improved. To this end, each CCN node has three functions: a CS (Content Store) for storing the content cache, a FIB (Forwarding Information Base) for delivering Interest packets towards the provider, and a PIT (Pending Interest Table) for forwarding Data

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packets towards the requesters. CCN is expected to reduce the number of content delivery hops and improve the content acquisition success rate.

Existing work on CCN [9][10] can be broadly divided into naming, caching, and routing [11]. In research on naming, it is possible to identify content information by hierarchical prefix [12]. This method differs from the proposed method in that it focuses on naming and is only effective when the content is static. To apply this to IVC, it is necessary to consider what should be classified as road / traffic information identifiers. As for cache, there is a study on cache management algorithm [13] to use cache buffer effectively. Although it has achieved promising results with excellent cache efficiency, it has the disadvantage of not being able to handle dynamic content. With respect to routing, it has been proposed that a city map be divided geographically and used for content search and routing by defining its own partition [14]. However, the CCN implementation is still an application layer overlay.

In conventional CCNs, naming, caching, and routing are usually addressed separately for the convenience of implementation. In IVC, vehicles move at high speed and network topology changes frequently. When CCN is implemented as an overlay in the application layer, it is necessary to update the FIB whenever the network topology changes, which causes a lot of overhead. In addition, the movement of vehicles also affects cache hit rate.

In CCN research, another method of caching with probability [15] is suggested to avoid redundant caching. There are various methods for calculating the cache probability, such as using the number of hops, using content popularity, or considering cache allocation. In this paper, we consider the influence of the wireless channel usage rate on the cache instead of the popularity because the lifetime of the content exchanged by IVC is short.

2.2 Routing

When CCN is applied to IVC, content distribution depends on the choice of relay vehicles. As for relay selection based on location information, the farthest vehicle is generally preferentially selected as a relay vehicle in order to improve relay efficiency [1]. In this way, the transmission distance in one hop can be extended as much as possible, and the number of hops required for dissemination can be reduced.

Packet reception status changes due to vehicle movement and channel fading in IVC. Vehicles that received a packet select the next relay vehicle in an autonomous and distributed manner based on the same position (distance) information. This share of position information between vehicles can be realized by using information exchange in the 700MHz band for driving safety support system [16]. The number of hops can be reduced by selecting the farthest vehicle within the communication range of the transmitter. Specifically, potential relay vehicles are sorted according to their distance (progress) from the transmitter, and their distance order is associated with different waiting time (in terms of slots) before forwarding. By assigning a shorter waiting time (an earlier slot) to a vehicle farther away from the transmitting vehicle, among all vehicles that are within the communication range of the transmitter and have received the packet, the farthest vehicle becomes the relay vehicle, because it starts forwarding in the earliest time, which makes other potential relays cancel their forwarding.

3. PROPOSED METHOD

Figure 1 shows the framework of the proposed methods, where the left side corresponds to the basic CV method, and the right side is its extensions, which further solve the cache miss problem in the mobile environment (ECV), and presents the cache optimization method based on channel usage rate (ECV+).

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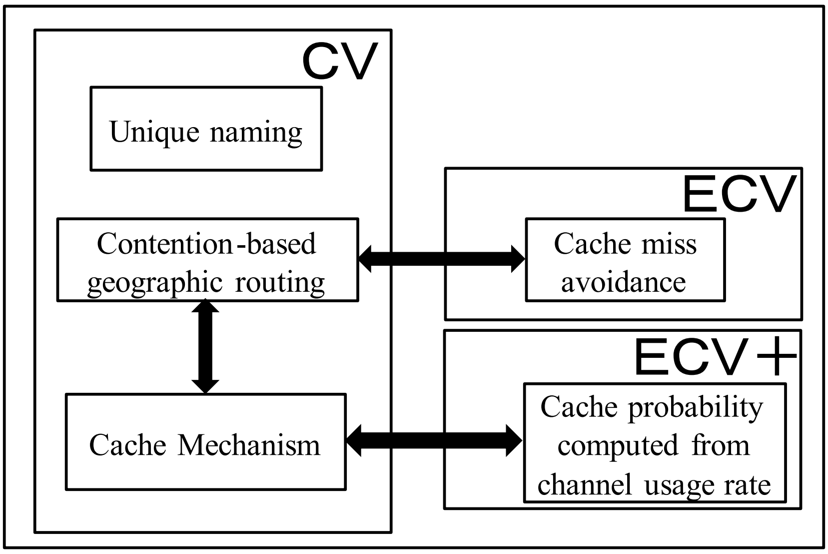

Figure 1 Proposed framework for applying CCN in IVC

3.1 CCN for Vehicle Network

CCN for Vehicle Network (CV method) is the baseline. In this method, we propose a naming mechanism and a routing mechanism for efficient dissemination.

3.1.1 Content naming (Solution of Problem 1)

The content name is composed of 1) geographic information and 2) road / traffic information indicating the type of event.

(1) Geographic information naming

Each intersection on the road is assigned a name (using coordinates), and intersection names are used as high level geographical information. Then, the name of the road link (hereinafter referred to as link) from intersection A to B is "AB". Intersection A is simply "A", and "AB / BC / C" shows the entire route from intersection A to C via links AB and BC.

(2) Naming of road and traffic information types

The names and values of the information types are listed in **Table 1**.

Table 1 Types of road and traffic information

Information type	Value
Passability judgment	Passable / not passable
Congestion	Normal / Slightly congested / Congested
Road surface condition	Normal / Freezing / Poor visibility, etc.

3.1.2 Routing (Solution of Problem 2)

The original definition of FIB and PIT in CCN is modified. Any vehicle that received an Interest packet can be a relay vehicle. Here, in order to improve relay efficiency, among the vehicles that have received an Interest packet, the vehicle farthest away from the transmitter (with the longest progress) is preferentially selected as the relay vehicle [1]. The location information of surrounding vehicles is shared in advance and compared instantly. Within the communication range of the transmitter, the longer distance (progress) a vehicle is from the transmitter, the shorter waiting time it is set in the MAC layer. In this way, the farthest vehicle is selected

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as the relay vehicle. The whole process consists of the following 3 steps.

I. After receiving an Interest packet, the relay vehicle is selected autonomously by setting the waiting time for the relay candidates. Figure 2 shows how the waiting time is set in terms of slots, where a vehicle with a longer distance has a shorter waiting time.

II. If the farthest vehicle has the required content in its cache buffer, it returns the content in the Data packet, otherwise it forwards the Interest packet.

III. A Data packet is forwarded in the same way as an Interest packet. A vehicle that overhears the Data packet keeps a copy in its cache buffer.

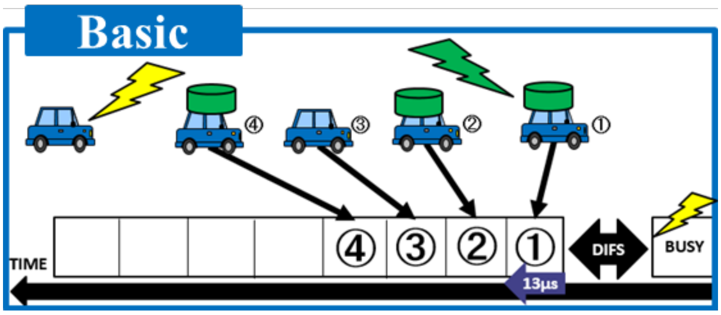

Figure 2 CV method

In the basic method, the cache miss problem occurs when the farthest vehicle in the communication range of the transmitter actually does not have the required content in its cache buffer, although other closer vehicles do. For example, a vehicle without required content becomes the farthest vehicle due to vehicle movement. In step II, if the farthest vehicle does not have required content in its cache buffer, it does not know whether vehicles behind it have the required content and decides to forward the Interest packet. In other words, each vehicle does not know whether surrounding vehicles have required content without causing much communication overhead, and then a cache miss occurs.

The other problem of the basic method is cache redundancy. A copy is kept on all vehicles that have received a Data packet. As a result, this hinders to efficiently use vehicle storage to store more contents.

This method does not consider the popularity which reflects how often a content is required. This is because a content in IVC has a short lifetime, and the popularity becomes meaningless whenever the content reaches its lifetime.

3.2 Extended CV Method

In order to solve the cache miss problem, we propose the Extended CV (ECV method) that realizes cache miss avoidance function. In the CV method, slot assignment for Interest/Data packet transmission is unified, and the decision of forwarding Interest packets and Data packets is based on the same slot. Because the vehicle farthest away from the transmitter does not know whether other closer vehicles have the required content, when itself does not have required content, it decides to start forwarding the Interest packet at its own slot, which may lead to the cache miss problem. In the ECV method, replying a Data packet and forwarding an Interest packet are divided into two separate stages, and replying a Data packet is given higher priority. Specifically, the ECV method first allocates slots for relay selection for replying a Data packet and then allocates different slots for relay selection for forwarding the Interest packet. If any vehicle with the required content replies a Data packet in the first stage, the relaying of the Interest packet is cancelled. Otherwise, the farthest vehicle continues forwarding the Interest packet as in the basic CV method.

Figure 3 shows how each vehicle is assigned two slots, one for Data packet and the other for Interest packet. The slots for the Data packet are assigned before those for the Interest packet so that any vehicle with the

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required content can reply a Data packet. Now the relay selection for replying the Data packet adopts a different policy, the closer a vehicle is to the transmitter (of the Interest packet), the higher priority it has, because a shorter distance generally means a higher transmission reliability. After that, the farthest vehicle is selected for forwarding the Data packet in the same way as for Interest packets. The slot allocation for Interest packet is the same as in the basic CV method.

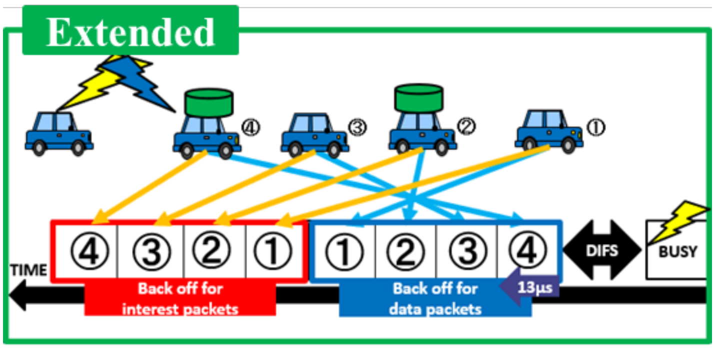

Figure 3 ECV method

In this way, cache hits if any vehicle holds the required content.

3.3 Further Enhancement of the ECV Method

We notice that when vehicle density is high enough, the cache hit performance will not deteriorate much even if the same content is cached only at some vehicles, compared to the case where all vehicles cache the same content. Therefore, probability-based cache management is introduced to better share vehicle cache buffer and improve cache efficiency, and this method is called ECV+. In the ECV method cache probability is always 1, whereas in the ECV + method, cache probability is p_{cache}<1 (p_{cache} changes dynamically).

If cache probability is too small in order to increase the diversity of cached content, cache hit rate may decrease, when a content is not cached by any vehicle and the number of hops will increase. As a result, the amount of communication increases and the channel usage rate increases. On the other hand, if the cache probability is too large, vehicles tend to cache the same content, and cache hit rate decreases if diverse contents are required but not hit in any vehicle, which also affects the amount of communication. Therefore, it is necessary to dynamically adjust the cache probability according to channel usage rate.

Based on the above description, the ECV+ method compares the channel usage rate before and after content delivery, and performs a heuristic feedback control of cache probability, in order to increase cache hit rate and avoid channel congestion. The whole process is described by Algorithm I, where the process is run periodically. Specifically, cache probability p_{cache} is adjusted based on past (ρ_{old}) and current (ρ_{new}) channel usage rate, to evaluate the effectiveness of the previous control. Since caching decision is probabilistic, redundant cache can be avoided, and the amount of cache is adjusted to an appropriate value by dynamically changing cache probability. Vehicle density, another factor that may affect cache probability, although not explicitly considered, is indirectly involved in the control.

Algorithm I: Control of cache probability

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ρ_{new} : Current channel usage rate
ρ_{old} : Past channel usage rate
ρ_{th} : Threshold of channel usage rate variation for triggering cache probability adjustment
ρ_{max} : Maximum channel usage rate
p_{cache} : Cache probability
Δ : Adjustment of cache probability
$\rho_{old} \leftarrow 0.5$
while (true)
    ρ_{new} = GetChannelUsageRate();
    if($|\rho_{new} - \rho_{old}| > \rho_{th}$)
        if ($\rho_{new} < \rho_{old}$ and $\rho_{new} < \rho_{max}$)
            $p_{cache} \leftarrow p_{cache} - \Delta$
        else if (($\rho_{new} > \rho_{old}$ and $\rho_{new} < \rho_{max}$) or $\rho_{new} > \rho_{max}$)
            $p_{cache} \leftarrow p_{cache} + \Delta$
    $\rho_{old} \leftarrow \rho_{new}$
    sleep for a period
GetChannelUsageRate() : Function to get channel usage rate

4. SIMULATION EVALUATION

Simulation evaluation is performed to evaluate the effectiveness of the proposed method. The number of hops (the average number of transmissions per data packet), and the content acquisition success rate per interest packet, are used as main performance metrics.

4.1 Comparison methods

Four methods, Non-Cache, CV, ECV, and ECV+, will be compared. Non-Cache does not use the cache mechanism of CCN. CV (Sec.3.1) is the baseline method that realizes the CCN function for IVC. ECV (Sec.3.2) is an extension of CV and solves the cache miss problem. ECV+ (Sec.3.3) includes all the proposed functions and improves cache efficiency by monitoring channel usage rate.

4.2 Simulation conditions

In the simulation, the actual map data obtained from the open street map is read into the network simulator Scenargie [17], and the shielding of the building is emulated. The simulation area used for the simulation is the Ginza area in Tokyo (Figure 4), which represents the urban area of Japan. Table 2 shows detailed simulation setting. The moving speed of vehicles ranges from 20 km/h to 30 km/h. Each traffic light changes periodically (period is 90 s). The information lifetime is 30 seconds. All vehicles issue Interest packets, and the target intersection of Interest packet is specified based on the popularity of intersections set according to the types of roads that make up the intersection.

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Figure 4 Simulation area (Ginza in Tokyo)

Table 2 Simulation setting

Item	Value
Network simulator	Scenargie [17]
Field	1600m × 1600m
Area	Ginza
Vehicle initial position	random
Vehicle speed	20km/h~30km/h
Total number of vehicles	300-700 units
Cache update	Least Recently Used (LRU)
Communication method	IEEE802.11p(5.9GHz)
Transmission rate	3Mbps
Packet size	Interest 256byte Data 512byte
Radio propagation model	Nakagami (with fading)
Information generation interval for each vehicle	1s~16s
Simulation execution time	300s
Number of executions	720 times
Buffer size	1GB~10000GB

4.3 Simulation result

Here, we show the simulation results using the cache buffer capacity, information generation interval, and vehicle density as parameters.

4.3.1 Results under different cache buffer capacity

When cache buffer capacity of each vehicle is changed from 1GB, 10GB, 100GB, 1000GB, to 10000GB, Figure 5 shows the variation of average number of hops, content acquisition success rate, cache hit rate, and cache probability, respectively. 95% confidence interval is also shown in each figure.

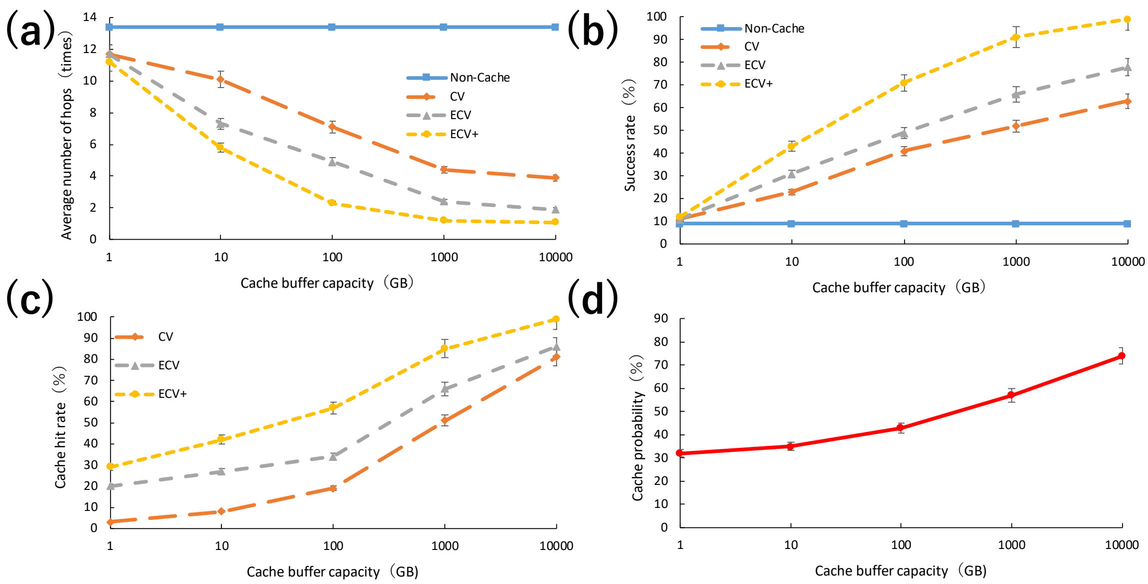

Figure 5 Results under different cache buffer capacity

As the cache buffer capacity increases, the average number of hops decreases (Figure 5a), while content acquisition success rate increases (Figure 5b). This is because more contents can be stored in the cache buffer and the cache hit rate improves as the cache buffer capacity increases (Figure 5c).

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The average number of hops of the three methods using CCN is almost equal at 1G. This is because only a few contents can be cached and cache hit rate is low. The average hop count decreases as the cache buffer capacity increases to 10G and 100G, but approaches steady values when the cache buffer capacity is increased from 1000G to 10000G, because with 1000G most contents can be cached. In the vicinity of 100G, the difference among different methods in the average number of hops is large: 13.4 for Non-Cache, 7.1 for CV, 4.9 for ECV, and 2.3 for ECV+. ECV+ reduces the average number of hops by up to 83% compared with Non-Cache, ECV reduces the average number of hops by up to 63% compared with Non-Cache and CV reduces the average number of hops by up to 47% compared with Non-Cache.

With the increase of cache buffer capacity, cache hit rate improves and the average number of hops decreases. So the probability of packet loss decreases, which leads to higher content acquisition success rate. When cache buffer capacity is 100G, ECV+ improves content acquisition success rate by about 45% compared with ECV.

The results in (Figure 5d) show that the cache probability in ECV+ tends to increase with cache buffer capacity. When the cache buffer capacity is 100G, the average cache probability is 36%, which means nearly 3 times of contents can be cached compared with ECV. As a result, ECV+ improves cache hit rate by about 68% compared with ECV. The cache hit rate of ECV+ is very high at 1000G (Figure 5c), and is almost 100% at 10000G, because the actual message volume is about 5000G.

4.3.2 Results under different information generation intervals

When the information generation interval is changed from 1, 2, 4, 8, to 16 seconds, Figure 6 shows average number of hops, content acquisition success rate, cache hit rate, and cache probability, respectively.

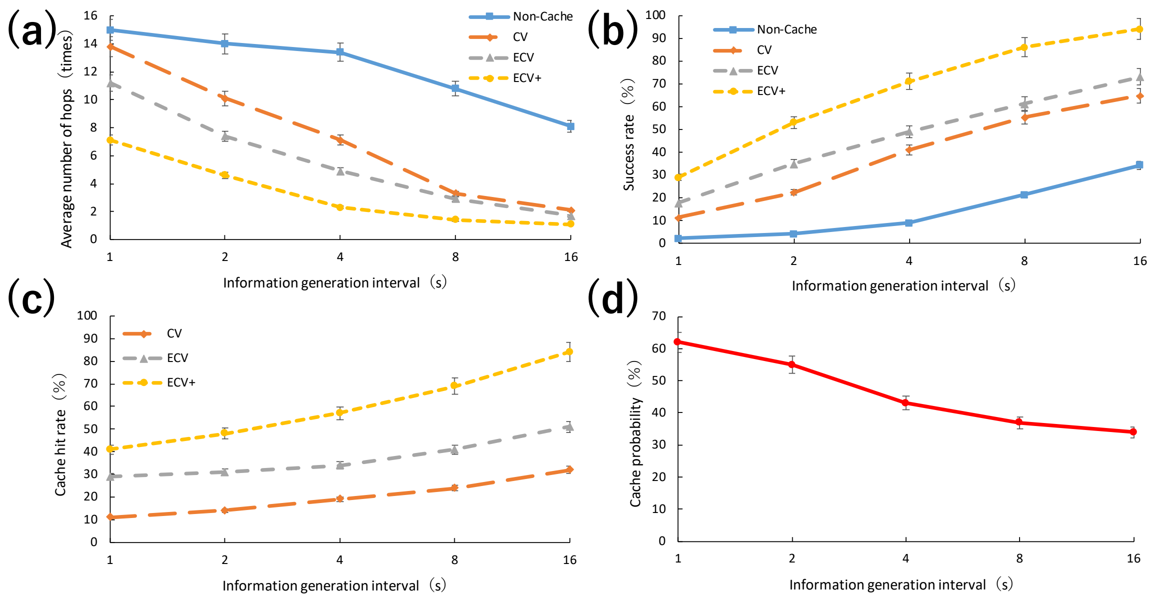

Figure 6 Results under different information generation intervals

As the information generation interval increases, channel usage rate decreases, and cache hit rate increases (Figure 6c). Accordingly, the average number of hops decreases (Figure 6a) while content acquisition success rate increases (Figure 6b). When the information generation interval is large (16s), most contents can be cached, and the performance difference among ECV+, ECV, and CV in average number of hops is not large. But when the information generation interval is small (1s and 2s), many messages lead to channel congestion. Under these severe circumstances, the average number of hops in all methods gets large, but ECV+ helps to

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greatly reduce the average number of hops, and achieve a much higher success rate, compared with other methods.

(Figure 6d) shows that cache probability decreases as the information generation interval increases. When the information generation interval is small, too much information leads to a high channel usage rate. So the cache probability is increased to suppress the channel usage rate.

4.3.3 Results under different vehicle density

When vehicle density changes, Figure 7 shows the variation in the average number of hops, content acquisition success rate, cache hit rate, and cache probability, respectively.

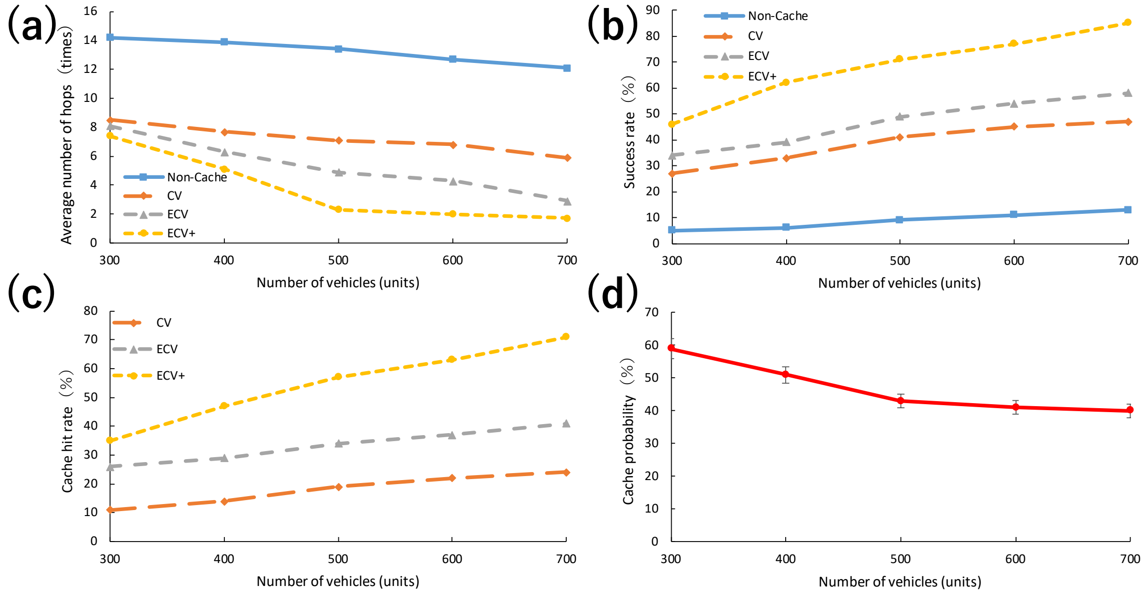

Figure 7 Results under different number of vehicles

As the vehicle density increases, the average number of hops decreases a little (Figure 7a). This is because more vehicles help improve network connectivity. Accordingly, content acquisition success rate increases (Figure 7b). ECV+ further exploits more vehicles to cache more contents (cache hit rate increases with vehicle density in (Figure 7c)), and achieves much higher performance than other methods.

(Figure 7d) shows that cache probability decreases as the vehicle density increases. This is because ECV+ tries to exploit more vehicles to cache more contents, and accordingly, the amount of content to be cached per vehicle decreases.

4.4 DISCSSION

Of the three parameters (cache buffer capacity, information generation interval, and vehicle density), the parameter that most affects the results is cache buffer capacity. With plain CCN (cache function), cache hit helps to reduce the average number of hops and improve the success rate of dissemination. When cache buffer capacity is too small (frequent update of cache buffer leads to low hit rate) or too large (most contents can be cached), the superiority of ECV+ is not very obvious. But with a moderate cache buffer capacity, ECV+ far outperforms other methods, and achieves better cost performance.

Information generation interval affects channel usage rate. Information generation interval of several seconds is used to evaluate the proposed method in severe conditions. Due to the nature of Pull-type delivery,

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information with low urgency is delivered by request, so the information generation interval is expected to increase in real scenarios, where the proposed method is expected to work well too.

Vehicle density has less impact on the results than the other parameters. One potential reason is that vehicle density is not explicitly taken into account in adjusting cache probability. But a big change can be seen when the number of vehicles gets larger than a threshold. On the other hand, if the number of vehicles is too small (which affects the connectivity), the result will be greatly deteriorated.

From the above discussions, the proposed ECV+ method improves performance more or less in different scenarios. If the cache probability can be controlled in a better way by machine learning (e.g., reinforcement learning), it is expected that the superiority of the proposed method will be more obvious.

5. CONCLUSION

We have proposed to apply CCN for efficient collection of road and traffic information via IVC. The importance of unique naming and topology adaptive routing has been verified before. By further including the dynamic adjustment of cache probability, the proposed ECV+ method greatly reduces the average number of hops by 53%, improves content acquisition success rate by up to 45%, and the cache hit rate by up to 68% compared with the previously proposed ECV method. The effect of the proposed method strongly depends on the cache buffer capacity of each vehicle. In order to maximize the effectiveness of the proposed method with limited cache buffer, cache probability is adjusted, based on channel usage rate.

In the future, in order to cope with more complicated vehicle-to-vehicle communication, we aim to apply reinforcement learning to adjust cache probability. In addition, since delivery by multi-hop communication depends on the vehicle topology, experiments in other urban areas and high ways will also be conducted.

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