Pre-handover Mechanism in the Internet of Vehicles Based on Named Data Networking

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Abstract. Named Data Networking (NDN) is considered to be one of the most promising designs for the next generation of network architecture. Vehicles are typically interested in the content itself than the location of the host. Owing to the content-centric attributes, NDN can support highly dynamic topologies more than the traditional host-centric communication mode. So it will be widely used in vehicluar networks. The moving vehicles are constantly handover between different roadside units (RSU), which affects the backhaul of data packets and increases transmission delay. Therefore handover in Internet of Vehicles (IoV)-based NDN is a challenge to be solved. In order to improve communication quality, this paper proposes a pre-handover forwarding mechanism based on RSU level and content popularity by establishing a probability model. Routing data packets in advance by predicting whether the content requested by the vehicle is cached in the RSU after handover. Thus the mechanism not only reduces delay, but also solves the problem of packet loss caused by network topology changes. In addition, in order to further improve content retrieval efficiency and reduce delay, this paper also proposes a method based on the tabu search (TS) algorithm to quickly search for the target vehicle within the coverage of the RSU. Simulation results show that the mechanism proposed in this paper outperforms existing related mechanisms in terms of average delay and delivery rate.

Keywords: Named data networking · Internet of Vehicles · Predication · Forwarding

1 Introduction

The Internet of Vehicles (IoV), a technical basis for intelligent transportation systems (ITS), plays an important role in the construction of smart cities. With the increasing demand for vehicle service, the IoV is attracting extensive attention in the field of communications. Each vehicle is equipped with an on-board unit (OBU) for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications in the IoV [1]. When the IoV is applied to a host-centric communication mode, the data packets are routed using IP addresses [2]. Due

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H. Gao et al. (Eds.): ChinaCom 2021, LNICST 433, pp. 335–347, 2022.
https://doi.org/10.1007/978-3-030-99200-2_26

to vehicles with specific addresses constantly change their locations, IP-based communication mode can no longer achieve stable and fast data access in such a dynamic network. To solve this problem, Named Data Networking (NDN) is applied to the IoV [3]. NDN changes the traditional host-centric communication mode to data-centric communication mode. The IoV-based NDN can not only improve the efficiency of content retrieval [4], but also improve the scalability of the network. Therefore the application of NDN in the IoV has become a research hotspot. In the IoV-based NDN, some areas concerning data packet forwarding [5,6], cache strategy [7,8], and naming method [9], etc., have attracted the wildly attention of researchers.

In the IoV-based NDN, consumer (vehicle) sends interest packets to the roadside unit (RSU) connected to it [10]. RSU is a communication infrastructure that mainly provides information such as road conditions and forwards data. In the IoV-based NDN, RSU is considered as a node in the NDN network and has the function of in-network caching. Consumer sends interest packets to the network, then the router in the network retrieves the corresponding content according to the interest packet. The content publisher (RSU or base station (BS)), encapsulates the content data into a data packet, then the data packet will return to the consumer along the forwarding path of the interest packet [11]. Due to the mobility of vehicles, the symmetric routing mechanism of NDN is destroyed, which may make the data packets loss in the forwarding process. Therefore the quality of experience (QoE) and quality of service (QoS) will be affected. For this reason, the research focus of the IoV-based NDN is to improve the success rate of backhaul data packet and communication efficiency in a mobile environment. To reduce the transmission delay, several mechanisms have been proposed. Handover of V-NDN based on RSU-assisted is proposed in [12], this mechanism is only considered V2R (vehicle-to-RSU) communication, without considering BS. In order to not interrupt the communication service, R. Chen et al. [13] proposed a fast handover mechanism in named data networking-railway, but this mechanism is only applicable to high-speed rail scenario. The schemes that reduce the authentication latency are proposed in [14,15], so that the mobile node can be authenticated in advance. An efficient handover [16] reduces the number of redundant handovers based on the received signal strength and wireless transmission loss in hierarchical cell networks.

Although the handover mechanisms for NDN and IP can reduce delay and improve communication quality. However, when the continuous changes in network topology occurs, these mechanisms cannot cope with the backhaul of data packets when consumers change frequently. They also cannot achieve seamless handover. Therefore, in this paper we propose a pre-handover mechanism based on RSU level and content popularity. The main contributions in this paper can be summarized as follows:

1. In the IoV-based NDN scenario, consumers are constantly moving, which destroys the symmetric routing mechanism of NDN and affects the backhaul of data packets. To solve the problem, this paper proposes a probabilistic model that considers both RSU level and content popularity, which used for predicting whether the content requested by the vehicle is cached in the RSU after handover.

2. When the RSU is going to return a data packet to the requesting vehicle, the idea of the tabu search (TS) algorithm [17] can be applied to search for the target vehicle within the coverage of the RSU to improve the backhaul efficiency.
3. Simulation is performed to show that the proposed mechanism in this paper can not only effectively reduce the delay of the vehicle handover between different RSUs, but also improve the success rate of the backhaul data packets.

The remainder of this paper is organized as follows. In Sect. 2, we illustrate the flow of the pre-handover mechanism and explain the probabilistic model for prediction in detail. In Sect. 3, a method of searching for the target vehicle quickly within the coverage of the RSU is proposed. Simulation results and analyses are presented is Sect. 4. Conclusions are drew in Sect. 5.

2 Proposed Pre-handover Mechanism

2.1 Pre-handover Application Scenario

At the road intersection, Due to the movement of the vehicle, the pre-handover process between different RSUs is shown in Fig. 1, which includes three parts: vehicle, RSU and BS. RSU is considered as a node in the NDN network. The data structure in each NDN node consists of three parts: Content Store (CS), Pending Interest Table (PIT) and Forwarding Information Base (FIB), where CS is used to store data, PIT is used to record the data request interface information that the node has forwarded interest packet but not yet satisfied, FIB stores forwarding the interface information and routes the interest packet according to the routing table. The process of node processing data packet is shown in Fig. 2.

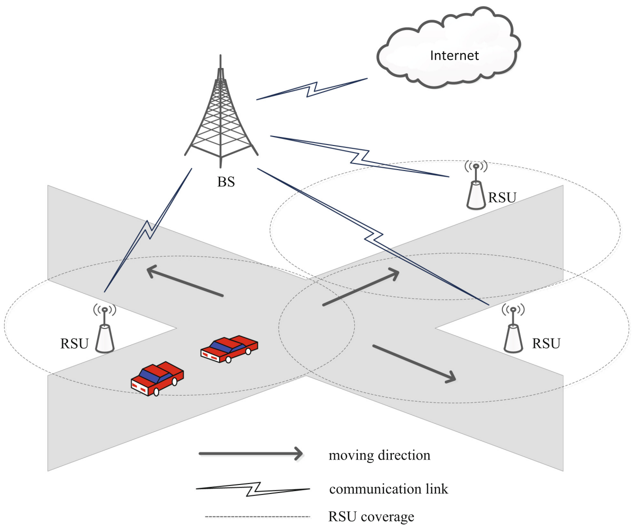

Fig. 1. Application scenario

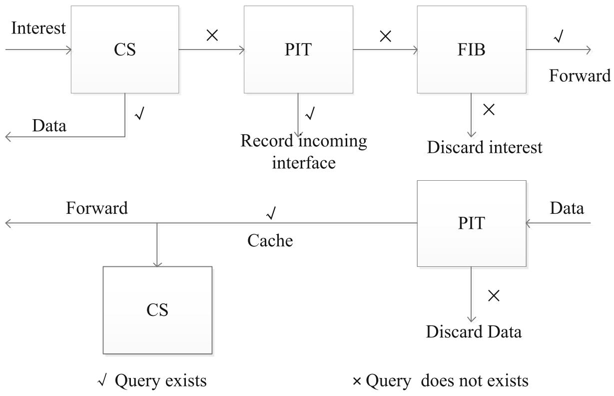

Fig. 2. The routing process of NDN node

2.2 The Routing Process of Data Packets

When the consumer sends an interest packet within the RSU coverage, the RSU will forward the interest packet to the producer (the content provider). According to the characteristic that the data packet returns along the forwarding path of the interest packet in NDN, the data packet will be forwarded back to the vehicle. Due to the mobility of the vehicle, vehicles in the RSU coverage change dynamically. At this time, the vehicle is going to leave the current RSU coverage, but has not received the backhaul data packet, the vehicle will send a Handover_Move packet to the RSU that is going to leave. The specific data packet format is shown in Fig. 3.

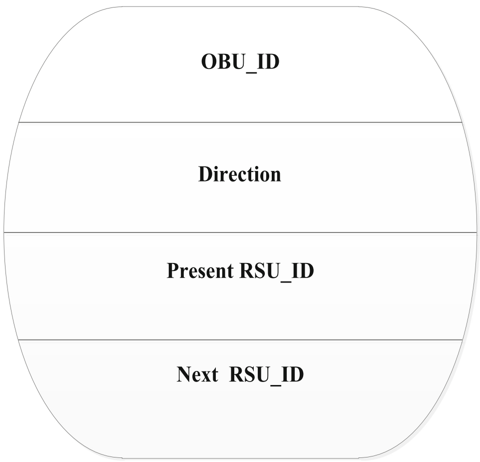

Fig. 3. Handover_Move packet

The Handover_Move data packet contains the vehicle number (OBU_ID), the direction of the vehicle (Direction), the present RSU_ID and the next RSU_ID. Among them, OBU_ID is the identity of the consumer, it facilitates the RSU to search for the target vehicle within its coverage. Due to the vehicle may be in a straight lane or at intersection, the direction is the direction of motion of the consumer after the handover. The present RSU_ID and the next RSU_ID are to prevent ping-pong handover [18]. For the ease of presentation, we denote RSU_A as the RSU before the handover, RSU_B as the RSU after the handover. After prediction, if the RSU_B is cached the content requested by the vehicle, the RSU_A will directly forward the interest packet to the RSU_B. The RSU_B will return a data packet to the requesting vehicle. If the RSU_B is not cached, the RSU_A will forward the interest packet to the BS while the vehicle is being switched. The BS returns the data packet to the RSU_B, then the data packet will be forwarded to the target vehicle through the RSU_B. The pre-handover routing processing is shown in Fig. 4.

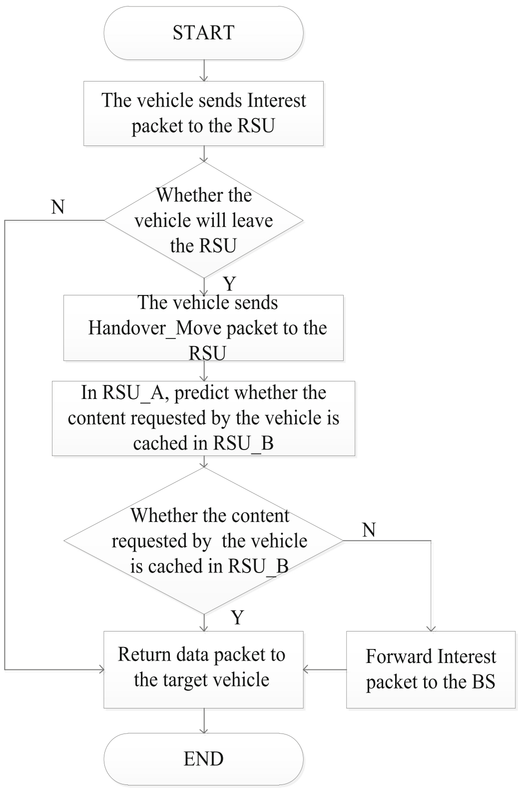

Fig. 4. Pre-handover routing process

2.3 Probabilistic Prediction Model

Because content caching is at the block level, the set of information items are cached in each RSU is denoted by $I = \{1, ..., i\}$, where i is the number of cached information items in RSU, there are j content blocks in each information item. Therefore there is a total of $n = j * i$ content blocks in each RSU. The popularity of content is characterized by the Zipf distribution. The content blocks cached in the RSU are divided into K categories according to their popularity, the set of the content category about popularity is denoted by $K = \{1, ...k\}$, where k is the popularity of the content block, where the popularity of 1 is greater than 2, etc.

Firstly, this paper classifies the RSU according to the two parameters of the 'quality' and 'quantity' of the cached content in the RSU. The so-called 'quality' refers to the popularity of cached content in the RSU. The quality of content in RSU increases as the popularity level of cached content increases. Since the content blocks in RSU are divided into K categories according to popularity, the 'quality' can be expressed by the weighted sum of RSU content blocks in different popularity levels, which is defined as event X. For example, the more content blocks with a high popularity level are cached in the RSU, the higher the RSU level. The more cached content blocks with a low popularity level, the lower the RSU level. The so-called 'quantity' is the total number of content blocks cached in the RSU, which is defined as the event Y. The more the number of content blocks cached in the RSU, the higher the level of the RSU. The less the number of cached content blocks, the lower the level of the RSU. Among them, the event X can be expressed as:

$$X = \frac{\alpha n_1 + \beta n_2 + ... + \eta n_k}{n} \tag{1}$$

In formula (1), n is the total number of cached content blocks in the RSU. $n_1, n_2, ..., n_k$ are the number of the content blocks at different popularity levels, where $n_1 + n_2 + ... + n_k = n$. $\alpha, \beta, ..., \eta$ are the weight coefficient of different popularity level, where $\alpha + \beta + ... \ \eta = 1$. The higher the popularity level, the greater the weight. Linear weighting is used to express the influence of content popularity on RSU level.

There are Q types of distribution of n content blocks on k content popularity levels, where Q is equal to

$$Q = C_{n+k-1}^{k-1} = \frac{(n+k-1)!}{n!(k-1)!} \tag{2}$$

through the analysis of the Q distributions of the content blocks. It can be concluded that the value range of X is between $[\eta, \alpha]$. In order to facilitate the analysis of the event of RSU level, the value of X needs to be normalized to the interval of 0 to 1, which can be shown as follows:

$$X_{nor} = X^{'} = a + k(X - X_{\min}) \tag{3}$$

where $k = \frac{(b-a)}{X_{max}-X_{min}}$, $a = 0$, $b = 1$, X_{min} and X_{max} are the minimum and maximum values of X respectively.

Event Y can be expressed as:

$$Y = m * n + l \tag{4}$$

where m and l are the coefficient of the linear function. The relationship between the number of cached content blocks in the RSU n and the RSU level G is linear positive correlation. Consequently, the RSU level increases with the increase of the number of cached content blocks in the RSU. In order to comprehensively evaluate the event of RSU level, the results of event Y need to be standardized, which can be expressed as follows:

$$Y^{'} = \frac{\log_{10}(m * n + 1)}{\log_{10}(m * n_{\max} + l)} \tag{5}$$

where n_{max} is the maximum value of the cached content in the RSU. Performing logarithmic conversion standardization processing for Y, to make the range of $Y^{'}$ between 0–1.

The RSU level is jointly determined by the event X and the event Y. Consequently the RSU level G can be expressed as:

$$G = X^{'} * Y^{'} = (\frac{\alpha n_1 + \beta n_2 + ... + \eta n_k}{n})_{nor} * \frac{\log_{10}(m * n + 1)}{\log_{10}(m * n_{\max} + l)} \tag{6}$$

where $(\frac{\alpha n_1+\beta n_2+...+\eta n_k}{n})_{nor}$ represents the influence of the content blocks at different popularity levels on the RSU level. The value range of $X^{'}$ is 0–1. In order to make the two events X and Y to determine RSU-level together, $\frac{\log_{10}(m*n+1)}{\log_{10}(m*n_{\max}+l)}$ represents the influence of the number of content blocks in the RSU. It needs to be standardized by logarithmic transformation so that its value is also between 0-1. Only in this way can a comprehensive evaluation of the RSU level be carried out. The quantitative processing of the RSU level is shown as follows:

$$G^{'} = \begin{cases} 1 \ \ if \ 0 < G^{'} \leq 0.2 \\ 2 \ \ if \ 0.2 < G^{'} \leq 0.4 \\ 3 \ \ if \ 0.4 < G^{'} \leq 0.6 \\ 4 \ \ if \ 0.6 < G^{'} \leq 0.8 \\ 5 \ \ if \ 0.8 < G^{'} \leq 1 \end{cases} \tag{7}$$

P is the probability of the content requested by the vehicle is cached in the RSU_B. It can be calculated as follows:

$$P = v * G + \mu * p \tag{8}$$

where G is the level of RSU, p is the popularity of the requested content. The probability of the content is cached in RSU is determined by the level of RSU G and the popularity of the requested content p. ν and μ are the weight of event

X and event Y, and $\mu > \nu$, $\nu + \mu = 1$. The distribution characteristic of the content request conforms to the Zipf-Mandelbrot distribution. Most users access a little part of the most popular content in the network, while most part of the content is rarely accessed. Hence, the higher the popularity of the content cached in the RSU, the greater the probability of being requested. The above probability model obtains the probability of the content requested by the vehicle is cached in the RSU_B. We can judge whether the RSU has cached the requested content through a preset threshold θ_p. If $P \geq \theta_p$, the requested content is cached in the RSU, if $P < \theta_p$, otherwise.

3 Routing of Backhaul Data Packets

The TS algorithm is an extension of the local search algorithm. In order to improve the shortcomings that the local search is easy to fall into the local optimal point. The TS algorithm introduces a tabu table to record the local optimal points that have been searched. In the next search, the information in the tabu table is no longer searched or selectively search, to jump out of the local best, and finally achieve global optimization. The so-called tabu is to prevent the repetition of the previous work. The algorithm applied to this paper is to quickly search and find the random mobile consumer within the coverage of the RSU. Since each vehicle is equipped with an OBU, it has a unique OBU_ID. Under the coverage of a RSU, the TS algorithm is used to search and match the OBU_ID of the vehicle, so that the backhaul data packet can be returned to the requesting vehicle at the fastest speed, which can ultimately reduce the communication delay. Moreover, the loss of data packet caused by vehicle movement will be mitigated. The specific search process is shown in Algorithm 1.

Algorithm 1. Routing of backhaul data packets

```
Collecting global nodes(vehicles) under the coverage of the RSU
Establishing dynamic candidate list SET_N(x) and an empty tabu list SET_T(x)
Once the vehicle leaves the coverage of the RSU, the corresponding OBU_ID of the
  vehicle needs to be deleted from the SET_N(x) in real time
Randomly select a node from the dynamic candidate list SET_N(x) for OBU_ID
  matching
for there are unsearched nodes in SET_N(x) and the target node is not found do
    if matching succeeded then
        the data packet is transmitted to the corresponding vehicle
    else
        the OBU_ID is added to the tabu list SET_T(x) prevent repeated searches
        In SET_N(x), randomly select a node from the neighborhood of the failed
  node to match
    end if
end for
```

4 Simulation Results and Discussions

In the simulation, this paper assumes that the position of the vehicle is randomly placed. The RSU is set to have a certain buffer to store data, while the BS is set to an infinite buffer to store data. In addition, there is no transmission conflict between them. The simulation is mainly aimed at analyzing the performance of traditional handover, V-NDN handover and pre-handover. The traditional handover based on IP, the vehicle needs to re-establish the connection with the RSU after the handover. The V-NDN handover based on NDN, the vehicle need to resend the request interest packet to the RSU_B after the handover. If the requested content is not cached in RSU_B, the interest packet must be forwarded to the content producer, this will increase the delay. The pre-handover based on NDN is to predict whether the requested content is cached in the RSU_B before the handover, the RSU_A routes data packets in advance to reduce transmission delay. This part mainly analyzes the average delay consumed during data packet transmission and the successful delivery rate of data packets. The simulation parameters are shown in Table 1.

Table 1. Simulation parameters

Parameter	Value
Number of consumers	5, 10, 15, 20, 25, 30, 35, 40, 45, 50
Number of RSUs	4
Number of BSs	2
RSU Range	400 m
Cache replacement	Least Recently Used (LRU)
Simulation time	100 s
Communication delay between RSUs	10 ms
Packet lifetime	2 s

The average delay can reflect the real-time nature of data transmission. Smaller average delay means better communication service quality. The successful delivery rate of data packets can reflect the stability of the data communication link. The higher the packet delivery rate, the better the stability of routing data transmission.

In order to evaluate the proposed pre-handover mechanism, we compare the average delay of different handover mechanisms. As shown in Fig. 5, as the popularity of the requested content increases, the handover performance of pre-handover is significantly better than the other two handover mechanisms. In the pre-handover mechanism, the RSU_A predicts whether the content requested by the vehicle is cached in RSU_B. If the requested content is not cached in RSU_B, the average delay is 40 ms. While if the RSU_B is cached, the average delay is 20 ms. The reason is that the pre-handover mechanism can handover the data packet in advance in RSU_A, which reduces the delay and improves content retrieval efficiency.

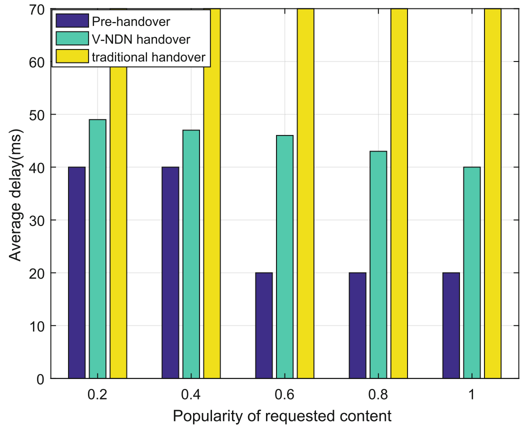

Fig. 5. The effect of requested content popularity on average delay

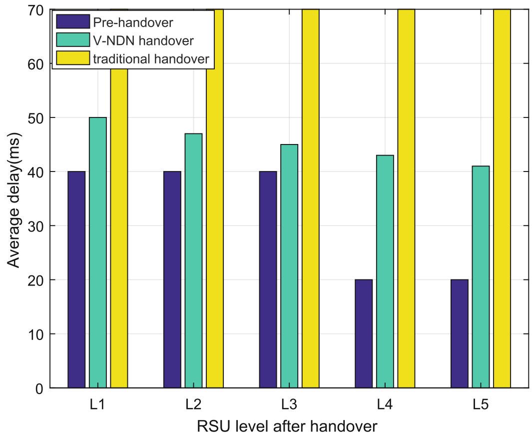

Fig. 6. The effect of RSU level after handover on average delay

Figure 6 shows the changes of the average delay with the level of the RSU_B increases. Compared with traditional handover, if the content is not cached, the pre-handover can reduce about 43% of the average delay. If the content is cached, the average delay can reduce about 71%. Compared with V-NDN handover, the pre-handover can reduce about 53% of the average delay in the highest RSU level. The reason is that traditional handover is based on IP, the change of RSU level has no effect on it. While the V-NDN handover and the pre-handover are both based on NDN, the pre-handover can route data packets in advance through prediction, which can reduce transmission delay.

Figure 7 compares the delivery rate of different handover mechanisms as the number of requested vehicles increases. As shown in Fig. 7, the delivery rate of the pre-handover is significantly higher than that of the V-NDN handover.

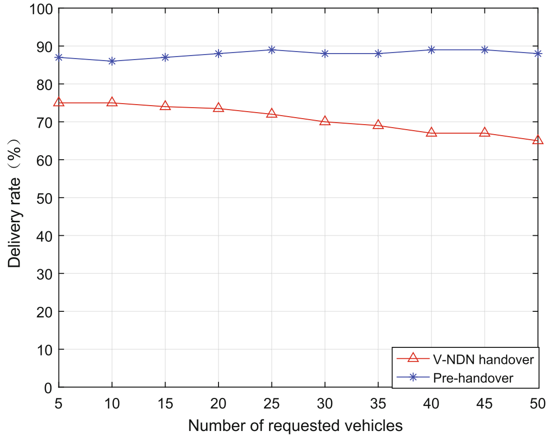

Fig. 7. The effect of the number of requested vehicles on delivery rate

As the number of requested vehicles increases, the pre-handover delivery rate hardly changes. While the delivery rate of the V-NDN handover has a certain downtrend. The reason is that the pre-handover process is completed through the cooperation of two RSUs. the handover delay is short. When there are many requesting vehicles, there is less pressure on the link, therefore the success rate of data packet delivery is high.

Figure 8 compares the change of the average delay of the pre-handover and the V-NDN handover, as the number of requested vehicles increases. In terms of delay, the pre-handover performance is better than V-NDN handover. When there are less requesting vehicles, the average delay of the two handover mechanisms changes the same. However, as the number of requesting vehicles increases,

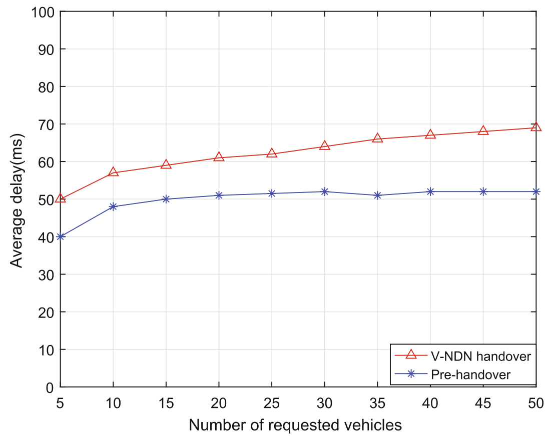

Fig. 8. The effect of the number of requested vehicles on average delay

the average delay of the V-NDN handover increases significantly. While the pre-handover almost stabilizes. The reason is that the handover delay of the pre-handover mechanism is little. When multiple vehicles request it, the mechanism has fast processing speed and is not easy to cause congestion. Consequently the average delay is short.

5 Conclusion

In order to solve the problem of network topology changes caused by vehicle movement and communication link failure in the IoV-based NDN. In this paper we proposed a pre-handover mechanism based on RSU level and content popularity. By establishing a probabilistic model, the vehicle can predict whether the content requested by the vehicle is cached in the switched RSU before the handover process. In order to further reduce the communication delay and increase the delivery rate of data packets, this paper also proposed a search method based on the TS algorithm, which is used to effectively search for the target vehicle within the coverage of the RSU. Finally, we analyzed the performance of the pre-handover mechanism from two aspects: average delay and delivery rate. In future research, we will further study the data transmission rules when both the requester and the publisher are on the move, and reduce the network consumption as much as possible in the combined V2R and V2V communication mode to improve the network transmission performance.

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