Delayed Broadcast-Based Data Forwarding Strategy for Vehicular Named Data Networks

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***Abstract*—In vehicular named data networks (VNDNs), the characteristics of high mobility and intermittent connectivity of vehicles bring challenges to stable communication between vehicle nodes. In addition, the consumer in named data networking (NDN) obtains data by broadcasting interest packets, and if it is not controlled, redundant packets will be generated, which will cause broadcasting storms. In response to the above problems, this paper proposes a delayed broadcasting-based data forwarding method. The method designs a data content discovery process that can obtain the location of the content producer before the data request, after which the forwarding timer is set according to the distance and relative speed, and the vehicle node with the shorter timer has a higher forwarding priority, effectively avoiding the generation of broadcast storms. The simulation results show that the method can effectively reduce the delay and improve the interest packet satisfaction rate.**

Keywords—Vehicular named data networks; delayed broadcast; data forwarding

I. INTRODUCTION

In recent years, the integration of computers, in-vehicle infrastructure, wireless communication, etc., with vehicles [1] has brought stronger technical support for the development of in-vehicle networks. A vehicle ad hoc network (VANET) facilitates vehicles to communicate effectively without communication facilities, and any vehicle can be used as a communication node to join the network to participate in data transmission, which has become an important research technology of intelligent transportation systems (ITSs). However, due to the high mobility of vehicles, signal quality instability, etc., vehicular applications must distribute a large amount of data among heterogeneous participants [2], communication link breaks lead to frequent addressing, and the current IP address-centered model of the internet is not applicable to highly dynamic environments in vehicular networking. Therefore, scholars are gradually advocating a shift from the traditional TCP/IP-based network architecture to a new type of information-centric network. Named data networking (NDN) is one representative research project.

Different from TCP/IP networks, NDN is a content-centric future network architecture that uses data names as unique identifiers for content lookup, and during data transmission, the requestor only cares about the content itself rather than where the data come from, which eliminates the complex IP addressing process in traditional network architectures. In addition, the in-network caching function provided by NDN makes it convenient for nodes to obtain data from nearby content producers without sending requests to specific nodes. These features of NDNs can help to improve the efficiency of sending and receiving data in the in-vehicle environment [3]; therefore, the vehicular named data network (VNDN) has gradually entered into the research attention of experts and scholars from various countries. VNDN combines NDN with VANET, aiming to improve the communication efficiency between vehicles and obtain a more efficient and faster data exchange experience.

Although there are many advantages of NDN applied to vehicle networking compared to traditional TCP/IP networks, how to solve the communication link breakage caused by nodes' high-speed movement and the broadcast storm problem caused by nodes' broadcasting remain key topics of current VNDN research. To address the above problems, this paper proposes a delayed broadcast-based data forwarding method, which broadcasts a lightweight beacon packet to detect the location of the producer vehicle before the consumer vehicle node interest packet (broadcasting is considered feasible because the beacon packet is lightweight), and after that, selects the node with the communication connection time that meets the time required for the packet returned from the nodes to be forwarded to participate in the delayed forwarding, and utilizes its distance from the producer vehicle and the relative speed with the previous hop node to set the forwarding timer. Once the timer is up, the node starts forwarding the interest packet, while other nodes with longer timers receive the same interest packet, proving that a node has already forwarded the interest packet, and then cancels the forwarding mechanism. This method can prevent repeated forwarding in the network and reduce redundant traffic while ensuring the smooth return of packets, improving the packet delivery rate.

In this paper, section Ⅱ gives a description of the current state of research on VNDN. In section Ⅲ, the delayed broadcast-based data forwarding strategy is described in detail. In section Ⅳ, the effectiveness of the proposed method is analyzed through simulation experiments, and finally, the paper is summarized in section V.

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II. RELATED WORKS

In recent years, with the deepening of research, NDNs have been applied to vehicular self-organizing networks, and a large amount of literature has been published, in which the main research focuses on how to solve the problems of data return failure due to path breaks and broadcast storms.

Neighbor-based forwarding strategy. In [4], the authors proposed a link stability-based content request interest forwarding protocol that controls the forwarding of interest forwarding vehicles. Although the above methods can improve the communication quality to some extent, the nodes must update the neighboring node information periodically, which entail high additional overhead for highly dynamic networks.

Location-dependent forwarding strategy. The authors in [7] proposed a listen-first-broadcast-later (LFBL) forwarding protocol for dynamic wireless networks, which leaves the forwarding decision to the receiver. After receiving a packet, a potential forwarding node listens to the channel waiting to see if there is a better node to forward the packet. This approach inspired the delayed broadcasting proposed in this paper. A fast traffic information dissemination scheme was proposed in [8], similar to LFBL, which uses timers to disseminate traffic information quickly. In [9], the authors proposed a delayed broadcast based on location information, where the forwarding timer is set by the distance between the forwarding node and the source node, as well as the target node, and the vehicle node with a short timer is given priority for forwarding. This method does not consider the link between mobile nodes' stability. The above two methods are not applicable to situations where the location of the vehicle of the content producer is not known.

Delayed broadcast with unicast. In [4], the authors proposed a delayed broadcast forwarding strategy called LISIC based on link maintenance time, which mitigates broadcast storms by using the link maintenance time to set a timer. The authors in [10] implemented the establishment of dynamic unicasts in CCNs in place of flooding. Inspired by this research, in [11], the authors proposed a scheme to build multiple unicast forwarding paths, where the consumer can build multiple unicast paths to multiple producers, and to optimize the network traffic, link expiry time and link availability probability are introduced to select the optimal path when building unicast links.

III. DELAYED BROADCAST-BASED DATA FORWARDING STRATEGY

In the proposed strategy, the consumer node first locates the nearest producer node position through the content discovery process before sending the interest packet. The

packets by giving preference to neighboring vehicles with more stable connections to the current sender, which mitigates broadcast storms to some extent. A scheme that aims to reduce packet collisions and error rates through a new relay node selection mechanism to eliminate packet retransmissions was proposed in [5]. The authors in [6] proposed a broadcast storm suppression strategy called BSMS, which uses the distance to the sender and the relative speeds to develop a priority level for selecting the next hop

consumer writes the obtained producer position information into the interest packet and broadcasts it. The surrounding vehicle nodes receiving the interest packet calculate the relative velocity to the previous hop and the distance to the producer and set a timer based on these two values. The node with the shortest timer has priority to forward the interest packet.

A. *Content discovery process*

The purpose of the content discovery process is to quickly obtain the location of the nearest producer to guide subsequent interest packet forwarding, avoid flooding, and optimize network traffic. Content discovery uses a lightweight message packet, whose structure is shown in Fig. 1. The beacon packet content includes the request data name (content name), the request vehicle id and survival time (the survival time is used to judge whether the beacon packet has expired), and the producer vehicle information (id, position, speed vector).

The content discovery process is shown in Algorithm 1: the consumer vehicle first broadcasts the beacon packet before sending the request, and the surrounding nodes receive the beacon packet. First, check whether it has expired or not; if it has, then discard it.Otherwise, check the Producer field. If it is empty, indicating that the beacon pac-

Algorithm 1: Content discovery process

```
Received:[Name,Consumer_ID,Producer message...]
If (the message has not expired) then
  If (the Producer filed is not null) then
    If (now node is consumer) then
      Add producer information to interest packet;
      Send interest packet;
    else forward the message;
    end if
  else
    if (Name in CS) then
      Add P_ID,P_position,P_velocity to Producer field in message;
      forward the message;
    else
      forward the message;
    end if
else
  delete the message;
end if
```

ket has not yet gone through the Producer vehicle, then query the CS table of the current node. If it matches the CS, write the current node id, location, and speed information into the beacon Producer field of the packet and broadcast it until the beacon packet is received by the consumer. If the CS is not matched, the beacon packet is broadcast and processed by the next node. If the Producer field is not empty, it indicates that the beacon packet has already passed through the producer node, and the next step is to determine whether the current node is the node requesting data. If so, the beacon packet has found the producer and obtained information such as its location, which will be added to the corresponding field of the interest packet. The improved format of the interest packet is shown in Fig. 2, with the addition of the consumer field, producer field and now node field, which record the information of the requesting node, the releasing node, and the current node, respectively, and this completes the content discovery phase. The producer in the beacon packet received first by the consumer is considered the closest producer.

B. *Delayed forwarding timer setting*

After the content discovery process, the consumer vehicle obtains the location information of the producer vehicle and adds it to the producer field of the interest packet. We chose to set the timer using distance and relative speed as reference indicators.

- The reason for using Euclidean distance as an indicator for setting the timer is that nodes closer to the producer can complete sending and receiving packets through fewer intermediate forwarding nodes, reducing transmission delay and the risk of link breakage.

$$dist_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (1)$$

  where x_i , y_i , x_j , and y_j are the coordinates of *vehicles i and j,* respectively.

- In general, we assume that the speed of the vehicles will not change drastically in a short period of time, and the smaller the relative speed is, the greater the possibility of maintaining a long-term connection between vehicles. Thus, the selection of forwarding nodes with smaller relative speeds to the previous hop node is more conducive to the successful sending and receiving of packets.

$$\Delta v_{i,j} = \sqrt{v_i^2 + v_j^2 - 2v_i v_j \cos(\theta_i - \theta_j)} \quad (2)$$

  where v_i , v_j denote the velocity of vehicles i, j; θ_i , θ_j denote the angles between the traveling direction of vehicles *i,j* and the horizontal direction.

After determining the two indicators to be used for setting the timer, we must consider how to unify the metrics of the two indicators. Because the two indicators represent different dimensions of the variable, independent of each other, and cannot be directly weighted, this paper adopts Z score standardization.

$$dist_i' = \frac{dist_i - \mu_1}{\sigma_1} \quad (3)$$

$$\Delta vel_i' = \frac{\Delta vel_i - \mu_2}{\sigma_2} \quad (4)$$

Before standardization, the required data are first sampled through several experiments to obtain the mean and standard deviation of the samples the data required for the experiment need to be sampled first. The speed of all vehicles in the experimental scenario is between 0~50km/h, which is in line with the actual driving speed of most of the vehicles on urban roads. In addition, in order to be closer to the real traffic scenarios, the initial position of the vehicle in the road and the initial speed are randomised, and the following model adopts the Krauss model in sumo, which is in line with the driving status of the vehicle in the real scenarios. For the sake of experimental rigour, this paper carried out 20 times of pre-simulation, and took the average value of the results as the experimental parameters of this paper. $\mu_1, \sigma_1, \mu_2, \sigma_2$ denote the mean and standard deviation obtained by sampling each of the two metrics, and $dist_i$, Δvel_i denote the distance of the node from the target node and the relative velocity to the previous hop, respectively. $dist_i'$ and $\Delta vel_i'$ denote the two metrics after demeasurement, which can be used to calculate the timer time.

$$delay\_timer_i = T_{hop} \times \frac{1}{1+e^{-(\omega_1 \times dist_i' + \omega_2 \times \Delta vel_i')}} \quad (5)$$

where T_{hop} indicates the maximum tolerable delay time and $\omega_1 + \omega_2$=1.

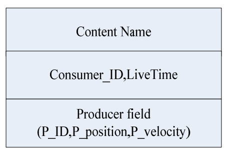


Fig. 1. Message structure

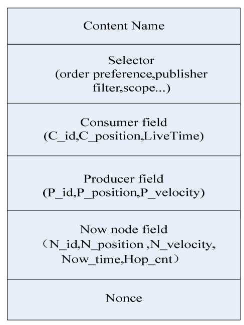


Fig. 2. Interest packet structure

C. *Data forwarding process*

1) Waiting Forward Table

TABLE I. WAITING FORWARD TABLE

Interest Packet	FT	ET
Interest_01	t_1+delay_timer$_1$	g_t_1+Live_time
Interest_02	t_2+delay_timer$_2$	g_t_2+Live_time

The WFT table contains three table entries, where FT indicates the interest packet forwarding time set by the timer, which is equal to the sum of the interest packet arrival time and the delay time, and the interest packet are forwarded when the time arrives. ET indicates the entry expiration time, which is equal to the sum of the entry creation time and the entry live time, and it is used to delete the expired entries and release the table space. The WFT table is updated in real time to guide the forwarding of interest packets.

2) Interest Packet Forwarding

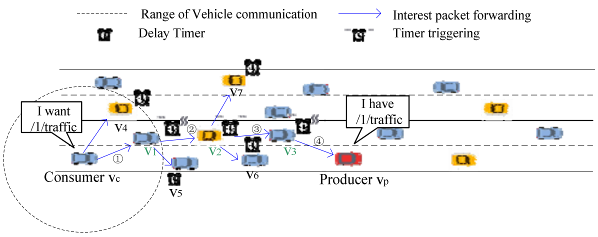


Fig. 3. Interest packet forwarding

Algorithm 2 describes the processing of the interest packet. As shown in Fig. 3, the consumer vehicle V_c first obtains the location of the nearest producer vehicle V_p through the content discovery process shown in Algorithm 1, after which it broadcasts the interest packet to the surrounding vehicles.

The neighboring vehicles that receive the interest packet first query the CS and send the data packet if it is cached. If there is no request data in the CS, then the WFT table is queried’ if there is, a vehicle node with a higher forwarding priority than the current vehicle has already forwarded the interest packet. To avoid useless duplicate forwarding, the forwarding timer is cancelled and the relevant entries in the WFT are deleted. If there is no match in the WFT, then continue to match the PIT. If the relevant entry is queried in the PIT, the current vehicle node has forwarded the interest packet and is waiting for the return of the data packet, add the incoming interface to the corresponding entry and discard the interest packet. If there is no match in the PIT, the neighboring vehicles V_1 and V_4 calculate their respective distances dst_i from V_p and relative velocities Δvel_i from V_c using Eqs. (1-2), and then use Eqs. (3-4) to obtain the normalized metrics dst_i', $\Delta vel_i'$. Theb, the two metrics are brought into Eq. (5) to determine their respective delayed forwarding times $delay\_timer_i$, and the entries are added to the WFT table. Assuming that V_1 has the shortest delay time, V_1 is the first to forward the interest packet while creating a new entry in the PIT and waiting for the data packet to return. Similarly, V_2, a neighbor of V_1, acquires the right to forward first, and then passes through V_3 until the interest packet is forwarded to the producer vehicle V_p. At this point, the interest packet forwarding process ends.

Algorithm 2: Received Interest packet in DBVNDN

```
Received:[Name,Consumer/Producer/Now nod message..]
    If (Name not in CS) then
      If (Name not in WFT)then
        If (Name not in PIT) then
          calculate dst_fp according to Eqs.(1);
          calculate Δvel according to Eqs.(2);
          calculate dst_fp and Δvel by Eqs.(3-4);
          calculate the delay_timer according to Eqs.(5);
          update Now node field in interest packet;
          add Interest packet, FT, ET to WFT;
        else
          add face to matching PIT entry;
        end if
      else
        delete Interest;
        delete the related entry in the WFT;
        cancel the forwarding process;
      end if
    else
      send Data Package to Face;
    end if
```

3) Data packet forwarding

In the data forwarding rules of NDN, data packets are passed back in reverse along the forwarding path of interest packets. When a vehicle node receives a data packet, it first checks the WFT table. If it is queried, the node is waiting to forward the same interest packet when a data packet has already been returned, so it cancels the delayed forwarding mechanism and deletes the corresponding entry. If there is no hit in the WFT, then it continues to check the PIT table. If it is queried, it means that the node has forwarded the same request for an interest packet. If the query indicates that the node has forwarded the same request interest packet and is waiting for the data packet to be returned, then the data packet is forwarded through the interface recorded in the PIT entry, and the corresponding entry is deleted. Moreover, the data are cached in the CS table to satisfy the request of the subsequent node. If the PIT is not hit, then the data packet is discarded.

IV. Simulation Results and Analysis

In this section, SUMO traffic simulation software is used to generate the vehicle trajectory required for simulation, and C++ is used to build the simulation platform to simulate the packet sending and receiving process of vehicles under the DBVNDN method proposed in this paper. The experimental scenario is set as a 2 km×2 km area, the speed of vehicles entering the lane is random and normally distributed. The main experimental parameters are shown in Table II. The impacts of the proportion of producers and the number of consumers on the interest packet satisfaction rate and the average delay are analyzed and compared with those of three existing schemes, namely, LISIC, BSMS and COVNDN.

The experimental results show that the proposed DBVNDN method has advantages in terms of both the interest packet satisfaction rate and average delay.

TABLE II. SIMULATION PARAMETERS

Parameters	Values
Simulation area	2 km×2 km
Speed	0~50 km/h
Transmission range	250 m
Consumers number	20, 40, 60, 80, 100
Producers percentage	5%, 10%, 15%, 20%, 25%
Live_time	30 s
one-hop transmission time	10 ms
Following model	Krauss model
Simulation time	150 s

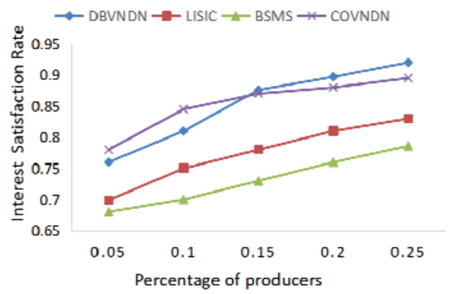
A. Vehicle motion data sampling

Sampling process: The experiment must obtain the mean and standard deviation of the relative speed and distance to the producer, so two experiments are performed. In different numbers of vehicles and road scenes, 50% of the vehicles were randomly selected for sampling, and the sampling interval was 10 s. The two indicators were calculated. Each experiment was performed 20 times to calculate the mean and standard deviation of the two indicators in all the sampling data.

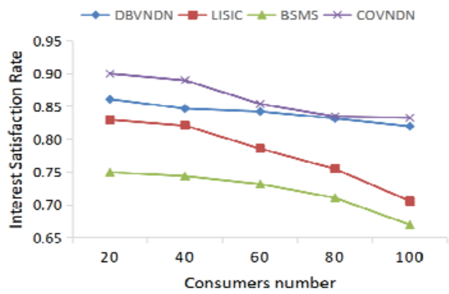
B. Simulation result

Interest Packet Satisfaction Ratio. This value is the ratio of the total number of data packets successfully received by consumers to the total number of interest packets sent. Fig. 4(a)(b) shows the interest packet satisfaction ratio versus the Producers' share and the number of Consumers.As shown in Fig. 4(a), with the increase of the proportion of producers, the satisfaction rate of interest packets of the four schemes gradually increases. As shown in Fig. 4(b), as the number of consumers increases, the interest packet satisfaction rate decreases for all four scenarios, because as the number of consumers increases, the number of requests in the network also increases, which leads to a corresponding increase in the number of unmet interest packets. In general, the DBVNDN proposed in this paper has a significant effect on improving the Interest packet satisfaction rate, this is due to the fact that when selecting the next-hop forwarding node,both its relative speed to the previous-hop and its distance to the producer are taken into account, and the two metrics are jointly constrained in order to select a forwarding node which not only maintains a more stable link, but also forwards the packet to the producer more quickly,thus improving the interest packet satisfaction rate.

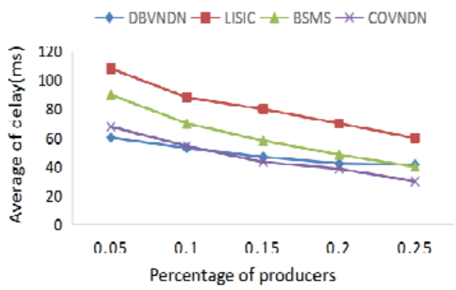
Average Latency. This value is the ratio of the sum of the time intervals between the sending of interest packets to the reception of data packets to the number of data packets successfully received. Fig. 4 (c)(d) show the relationship b-



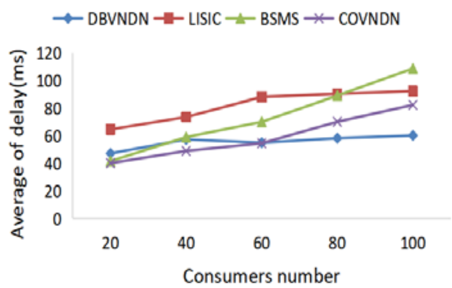
(a) Interest packet satisfaction rate varieswith the percentage of producers



(b) Interest packet satisfaction rate varies with the consumer number



(c) The average delay varies with the producer percentage



(d) The average delay varies with consumer number

Fig. 4. Performance comparison

etween the average delay and the proportion of producers and the number of consumers, respectively. As shown in Fig. 4(c), the average delay of all four schemes tends to decrease as the proportion of producers in the network increases, this is due to the fact that the average distance between the consumers and the producers in the network is smaller, which makes the process of sending and receiving data is completed more quickly. As shown in Fig. 4(d), the average delay increases with an increase in the number of consumers in the network. In general, the average delay under the proposed scheme is lower than that of the three other schemes regarding both variables, and the delay is lower under the same conditions.This is due to the fact that in DBVNDN, the node first locates the nearest producer through the content discovery process, and then through a timer mechanism so that only a small number of nodes with higher priority participate in the forwarding, which avoids Interest packet flooding and improves the communication efficiency and reduces the latency.

V. Conclusion

In this paper, we propose a data forwarding method based on relative speed and distance delayed broadcasting, using relative speed and distance to set timers to avoid broadcast storms. Experiments have proven that the method can effectively improve the data delivery rate and reduce the communication delay. In the next study, we will consider the combination of traffic information to predict the state of vehicle travel and guide the forwarding of interest packets through the prediction results.

Acknowledgments

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