Prediction-based Link Adaptive Forwarding Method in Vehicular Named Data Networking

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***Abstract*—Vehicular Named Data Networking (VNDN) is a communication architecture that applies the concepts of Named Data Networking (NDN) to Vehicular Ad-hoc Networks (VANETs). In VNDN, reliable data transmission under vehicular mobility conditions is critical for Quality of Service (QoS) support. To address the challenges of broadcast storms and unstable communication links in VNDN, this paper proposes a Prediction-based Link Adaptive Forwarding Method (PLAFM), which effectively mitigates reverse path disruptions while reducing Interest packet flooding. Experimental results demonstrate that PLAFM significantly improves communication efficiency and data delivery reliability.**

***Index Terms*—Vehicular named data networking, Vehicular ad hoc network, Quality of service, Prediction-based.**

I. Introduction

In recent years, Vehicular Ad-hoc Networks (VANETs) have garnered significant attention from both industry and academia. However, inherent characteristics such as intermittent connectivity and unstable signal quality make VANETs inherently complex in meeting application requirements and Quality of Service (QoS) provisioning. Compared to VANETs, Named Data Networking (NDN) demonstrates superior mobility support. Inspired by NDN's features, Vehicular Named Data Networking (VNDN) integrates the principles of NDN with VANETs, creating a communication architecture where vehicles request specific content by broadcasting Interest packets, while any nearby vehicle possessing the data can respond with corresponding Data packets [1]. Although VNDN enhances vehicular communication efficiency, it faces challenges during the content retrieval phase, including broadcast storms caused by Interest packet flooding and communication link disruptions due to high vehicle mobility.

To address these issues, we propose a Prediction-based Link Adaptive Forwarding Method (PLAFM). We introduce a reverse path maintenance mechanism and employ a Long Short-Term Memory (LSTM) model to predict the future movement states of vehicles. Through distributed heartbeat detection and local path repair, effectively mitigating reverse path disruptions. Additionally, it optimizes the Interest packet forwarding mechanism to resolve broadcast storm problems.

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II. Proposed Method

A. LSTM Structure

The LSTM controls information retention and transmission through its forget gate, input gate, and output gate, ultimately reflected in the cell state and output signal.

Each vehicle maintains a Neighbor Table (NHT), which records key information of neighboring vehicles within communication range across two time steps. By leveraging the movement states of neighbors from the past two time steps, we predict their future movement states. Each neighbor is individually fed into the LSTM model with the following input-output structure:

$$\text{Input Shape} = (N_{\text{neighbors}}, T_{\text{seq}} = 2, F_{\text{features}} = 3) \quad (1)$$

$$\text{Output Shape} = (N_{\text{neighbors}}, F_{\text{target}} = 3) \quad (2)$$

Where $N_{neighbors}$ denote the number of neighbors for the current vehicle (each neighbor is processed independently), T_{seq} be the sequence length (historical time steps $t-2$ and $t-1$), and $F_{features}$ is the feature dimension (X_j,Y_j,V_j), F_{target} is the feature dimension ($\hat{X}_j$, $\hat{Y}_j$, $\hat{V}_j$).

B. Calculation of Weight

This paper designs a weight calculation method that will be applied to two scenarios: Interest packet forwarding and neighbor selection for reverse path updates. We consider node adjacency to ensure that newly selected forwarding nodes may have previous hop nodes from the existing path within their communication range, enabling packets to be successfully transmitted along the reverse path. Additionally, we prioritize vehicles with similar moving directions and smaller relative velocities as next-hop candidates. The weight calculation is given by the following formula:

$$W_j = A_{ij} \cdot (w_1 \cdot D_{ij} + w_2 \cdot (1 - \frac{|v_i - v_j|}{V_{max}}) \cdot 100 + w_3 \cdot \theta) \quad (3)$$

In the formula, $w1$, $w2$, and $w3$ represent importance weighting factors, which are determined by the road environment. v_i and v_j denote the velocities of vehicle i and j respectively, normalized by V_{max}. θ is the relative angle. D_{ij} indicates the inter-node distance. The adjacency factor A_{ij} equals 1 when D_{ij} is less than the communication range diameter, otherwise 0.

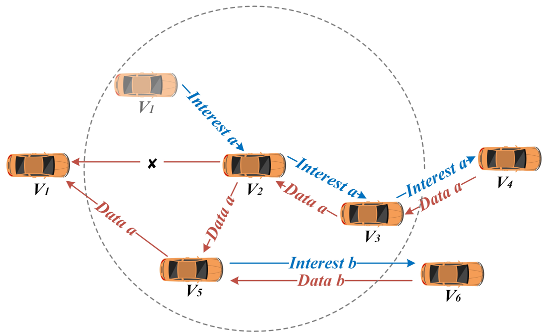


Fig. 1. The process of data transmission

C. Reverse Path Maintenance

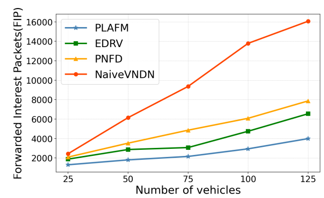
All vehicles periodically broadcast lightweight beacon packets to exchange mobility information with neighbors, which is stored in their NHT. As shown in the Fig. 1, if the distance between current vehicle v_2 and its upstream node v_1 exceeds a predefined threshold, the reverse path initiates distributed heartbeat detection. The adjacent nodes (both upstream and downstream) along the reverse path will periodically send lightweight heartbeat packets to v_1. If the end-to-end delay increases for three consecutive heartbeat packets, the path is deemed unstable and triggers immediate local repair. Vehicle v_2 employs LSTM to predict neighboring vehicles' mobility patterns, then calculates weights using Equation (3) to select the highest weight value vehicle v_5 for path repair. Finally, v_5 updates its PIT by adding the incoming interface (previous hop from the original path) upon receiving v_2's notification, thereby joining the reverse path.

D. Data Forwarding Process

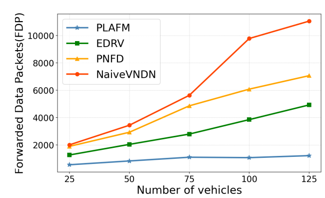
During the data discovery phase, an enhanced Interest packet forwarding mechanism is employed. Each vehicle utilizes historical neighbor information (from time steps $t-1$ and $t-2$) stored in its NHT to predict future neighbor states (time $t+1$) through an LSTM-based prediction model. Based on these predicted mobility patterns, Equation (3) is applied to compute a weighted metric for each neighboring vehicle. The neighbor with the highest weight value is then selected as the next-hop forwarder. When the Interest packet is ultimately satisfied after multi-hop forwarding, the corresponding Data packet follows the established reverse path back to the requesting consumer vehicle. Throughout this transmission process, continuous reverse path maintenance is performed in real-time to ensure reliable delivery until the Data packet reaches its destination.

III. Simulation

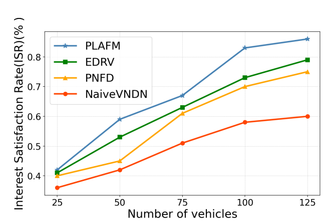
This section presents a comparative evaluation of PLAFM against existing EDRV [2] and PNFD [3] methods. The simulation environment was constructed using SUMO traffic simulation software to generate road networks and vehicle trajectories, with the simulation platform implemented in C++. The experiments were conducted in urban road scenarios, where vehicle speeds followed a normal distribution within the range of 0-80 km/h. All simulation results represent averages from 20 independent runs. The LSTM model employed AdamW as its optimizer, with a global learning rate set to 3e-5, the batch size was 64, the dataset was randomly partitioned into training, validation, and test sets following a 6:2:2 ratio.



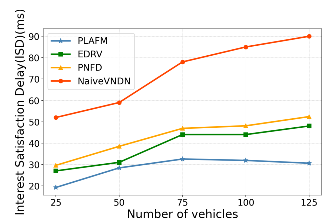
(a) Forwarded interest packets



(b) Forwarded data packets



(c) Interest satisfaction rate



(d) Interest satisfaction delay

Fig. 2. Comparisons of different approaches.

As shown in Fig. 2(a), the FIP of all strategies increases with vehicle density, while PLAFM outperforms others by reducing Interest packet forwarding. Fig. 2(b) demonstrates PLAFM's effectiveness in maintaining reverse path and reducing data retransmissions, thereby lowering FDP. In Fig. 2(c), PLAFM's adaptive data forwarding algorithm achieves higher ISR compared to other schemes. Fig. 2(d) shows that PLAFM uses an enhanced Interest packet forwarding mechanism that effectively addresses reverse path instability and reduces ISD.

IV. Conclusion

This paper proposes a Prediction-based Link Adaptive Forwarding Method (PLAFM). The method dynamically maintains reverse path according to varying network conditions while incorporating an enhanced Interest packet forwarding mechanism to mitigate broadcast storms. Experimental results demonstrate that PLAFM achieves higher Interest satisfaction rates and lower latency, effectively improving content delivery efficiency.

V. Acknowledgments

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