A Visual-Identification based Forwarding Strategy with Road Junction in Vehicular Named Data Networking

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***Abstract*—Named Data Networking (NDN) has emerged as a promising technique for addressing the current challenges associated with high dynamic mobility and intermittent connectivity prevalent in Vehicular Ad Hoc Networks (VANETs) [1]. However, the application of NDN in typical urban scenarios, where network segments are intricately interconnected, complexity to network communication and traffic congestion in junction areas. In our previous research, we proposed a concept of leveraging the cameras equipped on vehicles to devise a visual identification-based forwarding strategy that facilitates traffic information forecasting services in straight road scenarios [2]. Although visual information-based approaches offer advantages in terms of accuracy and performance, they require certain refinements. This study presents an enhanced method that involves the deployment of assistance nodes at junctions to support routing. Furthermore, this study introduces a novel naming scheme designed to efficiently obtain traffic information through prefixes in a lightweight manner. The experimental results demonstrate that the proposed strategy exhibits better performance, making it particularly well-suited for specific VANETs services when compared to prior approaches.**

***Index Terms*—wireless networks, ad-hoc networks, vanets**

I. INTRODUCTION

NDN has emerged as a promising technology that operates independently of the traditional IP-based approach by focusing on the retrieval of information objects based on their content names rather than on host endpoints. In NDN, communication revolves around two main packet types: Interest and Data. When a consumer seeks specific content, they initiate the process by sending an Interest packet containing the name of the desired content. Upon receiving this Interest packet, the content's producer responds by providing the corresponding content data in a Data packet, which is then sent back to the consumer. NDN routers play a crucial role in this process by facilitating the transfer of Data packets and caching them for future use. While NDN was originally designed for wired network topologies, its on-demand approach has proven to be highly adaptable to various network configurations, such as Vehicular Ad Hoc Networks (VANETs), characterized by their dynamic topologies and the inherent challenges in maintaining nodes and routes. Similar to the traditional IP-based architecture, NDN employs a routing process that involves the construction of a Forwarding Information Base (FIB) table. However, this is because of the substantial cost associated with the discovery phase of NDN routing. Our previous work [2] introduced a visual-identification-based forwarding strategy that employs an unicast-based approach in Vehicular Named Data Networking (V-NDN) to solve this issue. Vehicles gather information from their surroundings and assign a unique ID based on visual identification information. This visual ID serves a role similar to other identifiers such as MAC addresses or node IDs and plays a crucial role in forecasting traffic conditions. The evaluation results demonstrate that it enhances communication in V-NDN, making it more reliable, efficient, and reduces network overhead. However, this study primarily focused on a scenario involving straight roads. In practical urban road scenarios, the complexity is considerably higher because of the intricate network of roads connected via junctions. Junctions represent the most congested points in urban areas, as vehicles enter from multiple directions, leading to significantly increased communication demands. Moreover, once packets are routed to a junction, several challenges can rise [3] [4]. Previous, as discussed in [5] and [6] introduced the concept of assistance nodes at junctions to aid in the routing process. These assistance nodes are capable of maintaining the connectivity information at each junction to inform forwarding decisions. However, these existing solutions may not be entirely suitable for specific services, such as traffic condition forecasting, which requires periodic updates along all paths leading to a pre-defined destination.

Regarding safety information, a road trip comprises multiple segments and junctions, and ensuring the comprehensive monitoring of these elements is of utmost importance. Therefore, the central concept of this study involves harnessing the hierarchical naming scheme inherent to NDN to represent traveled roads in correspondence with the routing path. Additionally, forwarding becomes a challenge because of camera angles and intricate forwarding directions at junctions. The introduction of assistance node is indispensable, to monitor the current link status of each road segment, make transmission decisions. In this paper, we extend our previous proposal for applicability to typical urban scenarios by incorporating of assistance nodes at each junction. Second, we conduct an evaluation of the proposed approach, comparing it with related research works, including the traditional V-NDN [7] protocol based on beacons and the MMM-VNDN [8] protocol utilizing flat forwarding.

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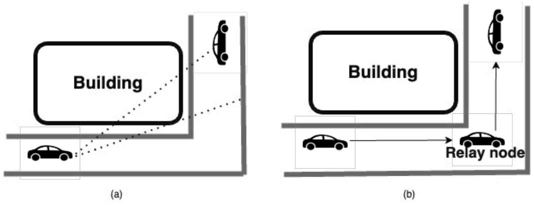
Various performance metrics, such as delivery ratio, end-to-end delay and average hop-count were examined. These evaluations illustrate the efficiency of the proposed protocol in supporting driving assistant applications.

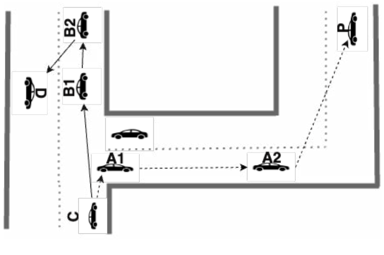
II. RELATED WORK

A. Packet Forwarding in junction and current issues

In a road network, junctions serve as critical components that facilitate the interconnection of various road segments and assist vehicles in the selection of new paths. Junction regions typically experiencing higher traffic density compared to road segments between two junctions [9]. The is because at junctions, vehicles from multiple directions converge or wait to make decisions regarding their route. In addition, there are two notable issues in such scenarios, namely, non-line-sight (NLOS) transmission [3] and packet forwarding across junction (PFAJ) [4]. In Fig. 1(a)(a) at the corner, NLOS transmission occurs when a packet is transmitted over a shared medium but encounters an obstacle, resulting in disruption of the communication path. Conversely, in the scenario depicted in Fig. 1(a) and (b), rather than transmitting the packet directly, it is relayed through an intermediate node located within the junction to prevent packet loss. When a vehicle approaches a junction, it sends a packet across the junction without complete visibility of the network topology, as illustrated in Fig.1(b). In this scenario, C, instead of sending the packet to A1 and following path A1-A2 in the right direction toward destination P, C forwards the packet directly across the junction to B1, which is the node furthest from C. Subsequently, B1 transmits the packet to B2, and B2 moves in the wrong direction away from destination P. Furthermore, B2 forwards the packet to an opposing D, ultimately leading to packet loss in this complex situation.



(a) The non-line-of-sight transmission



(b) Packet forwarded across junction

Fig. 1: Two main problems of routing at junction

Several approaches have been explored to mitigate network traffic congestion in junctions. In [5], researchers introduced the concept of setting up static controller nodes at the junctions. This controller nodes calculate the ratings for connected roads on the basic of parameters such as the number of network gaps or the expected transmission delays. All packets are forwarded to the assistance node at the junction, where they await a decision on the next direction. Similarly, in [6], the authors proposed using an assistance node at junctions. The assistance node stores and forwards packets when the appropriate conditions are met, while also measuring packet forwarding delay in real-time. Both of these methods successfully address issues such as NLOS and PFAJ, but they have high costs due to the lack of knowledge of the consumer's specific road trip and leads to a higher delay that may not meet safety requirements.

Taking these considerations into account, the concept of utilizing an assistance node at the junction to support routing remains favorable. However, many existing forwarding schemes do not adequately account for vehicle movement. By focusing on the specific needs of vehicles along their routes that are relevant to their specific location and route, these approaches can lead to more efficient, accurate, and less congested communication, which is crucial for applications like traffic-forecasting and safety-critical services.

B. Motivation

Previously, we introduced a concept to support driving assistance applications that require the real-time acquisition of road information [2]. The fundamental concept involves the utilization of a control-packet-free approach to encourage surrounding nodes to select the next candidate forwarder. Vehicles leverage front and rear cameras to extract visual information, such as license plate numbers, and assign them as identifiers referred to as Visual Identifiers (VIs). These VIs are then incorporated into the fields of Interest and Data packets, as shown in Table I. The VI of the next forwarder is placed in the Receiver-VI field of the Interest packet, whereas the sender's VI is added to the Sender-VI field for subsequent return communication. This approach enables unicast-based forwarding to the next node, effectively preventing broadcast storms [10], as illustrated in Fig. 2.

However, this work is primarily designed for straight roads, where routing paths are linearly established along road segments. When packets reach a junction, this routing protocol is inadequate, which leads to several issues.

- Camera angles at junctions are constrained, which can hinder the accurate capture of Visual Identifiers (VIs).
- The underlying concept of this strategy revolves around continuously sending Interests to gather road information as the vehicle moves forward. However, when an Interest packet arrives at a junction, it lacks information about the intended direction for the next direction.
- In the absence of controlled forwarding rules at the junctions, the problems mentioned in Section II-A may persist, leading to suboptimal routing decisions and other potential issues.

TABLE I: Parameter of Interest and Data packet

Interest	Data
Sender-VI	Sender-VI
Lifetime	Lifetime
Nonce	Nonce
Name	Name
Receiver-VI	Receiver-VI

These challenges highlight the need for a more comprehensive and adaptable routing strategy, particularly at road junction, where the existing protocol packets are dispersed in all directions at junctions. Moreover, the traffic volume processed at junctions becomes substantial, leading to redundancy and congestion problems, particularly when packet classification is not applied. Based on these considerations, our modifications address these challenges and adapt the protocol to typical urban road scenarios and transition from collecting information on straight roads to gather information for each individual vehicle flow. The key modifications proposed are as follows:

1) A novel naming scheme is introduced to classify packets based on their associated vehicle flows. This classification leverages the advantages of the hierarchical naming scheme inherent to NDN. The protocol can differentiate and manage traffic more effectively by categorizing packets based on their vehicle flow.
2) Assistance nodes were deployed at each junction within the network. These assistance nodes enhance the routing performance specifically for packets belonging to classified vehicle flows.

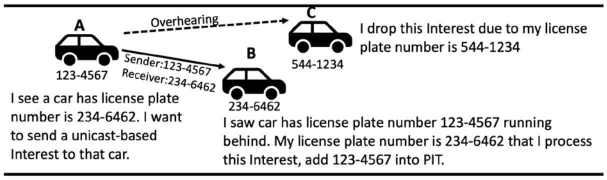


Fig. 2: Visual-identification based forwarding

III. PROPOSAL

A. Overview

We have several enhancements for our previous work [2] to facilitate a forwarding strategy that relies on the traveled road. It is able to support for not just straight road, but also intersections and road junctions. Our design is summarized by the following key elements:

1) We assume that vehicles follow pre-defined routes guided by a car navigator system, and consist of a series of segment-to-segment links. To accommodate this, we introduced a novel naming scheme for Interests and Data packets within the NDN framework. This naming scheme aligns with the specific route taken by the vehicle, dividing the prefix into components associated with individual segments. This approach allows the transmission of Interest packets along the vehicle's route, facilitating the retrieval of road information for each segment.
2) At each junction, we deploy an assistance node to play an important role in the routing process, all of which pass through these assistance nodes, where it awaits routing decisions. We assume that all junctions are uniquely identified using a numeric ID system. Additionally, vehicles, guided by the navigator, possess knowledge about these junctions. The assistance node continually maintains gateways for each direction, ensuring that incoming Interests are forwarded to an eligible forwarder with the same destination closest to the assistance node. In situations in which no appropriate forwarder is available, the assistance node temporarily stores the packet until a suitable path is identified, after which it is either forwarded or dropped. This approach optimizes routing efficiency and decision-making at junctions, catering to complex dynamics of urban road networks.

B. Naming scheme and Data

In this section, we introduce a hierarchical naming scheme designed to facilitate traffic information dissemination. Similar to the default NDN structure, our prefix is divided by '/' and further segmented into subcomponents to convey the flow of vehicles pre-routed by navigation, as illustrated in Fig.3. Notably, we leverage this naming scheme to eliminate the need for native Data packets in our design by representing all pertinent but non-content-specific information regarding traffic conditions and the return Data packet no longer contains data content but comprises the prefix exclusively. As an example, through the use of the "hierarchical prefix," the driver gains awareness of specific events like "/accidents" or "/congestion," as well as details regarding the time and location of these events, which will be explained later. Consequently, the content of vehicle flow can be represented using the following: *current_time/seg(1_2)/.../seg(n-1_n)*. The first prefix component *current_time* signifies the initial time of the Interest packet. The subsequent subcomponent *segment_ID* is constructed from pairs of junction IDs that represents the next sequential destinations where traffic information is required.

For example, in Fig. 3(a) we have vehicle traffic flow from 0 to exit 7: 0-1-5-6-7. To gather all information along this flow, the vehicle initiates an Interest packet with a prefix constructed as shown in Fig. 3(b), which consists of the names of the two junctions it connects, and intermediate nodes forward this Interest packet based on its hierarchical prefix.In contrast, the Data packet structure used for representation was as follows:

current_time/event_name/original_location/current_location.

The */timeline* component signifies the time at which the Data are generated, which serves to update the traffic status for the same event. */event-name* denotes real-time traffic events. The next component, */original-location* and */current-location* encompasses a set of source-destination pairs, reflecting the areas where the event occurred and the original Consumer's area for Data retrieval.

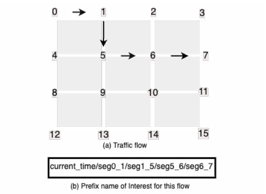


Fig. 3: Prefix name for corresponding to vehicle flow

C. Assistance node

In a typical urban scenario, where segments are interconnected through junctions and vehicles move from junction to junction, we deployed an assistance node at each junction to aid packet forwarding. To prevent undesirable forwarding of packets across junctions, our design mandates that all packets be relayed through the assistance node. In previous studies, the assistance node employed original tables individually. Similarly, our assistance nodes also maintain two original tables: the Incoming Packet Table (IPT) and FIB table for each exit. In our operational framework, vehicles transmit Interests along a straight road until they approach a junction within the transmission range of an assistance node (typically within 200 m). At this point, the vehicle identifies the next junction ID on the basic of the seg_id component that corresponds to its current location. It then inserts this junction ID into Receiver-VI field of the Interest packet as explained in the SectionII-B and transmits it as an unicast packet to the assistance node. The assistance node receives all incoming packets and utilizes them to construct the Incoming Packet Table (IPT), as shown in Table II(a), which monitors the traffic of vehicle flows and make informed next-hop selections for the available directions. By examining the prefixes of incoming Interests, the assistance node gains insights into the vehicle flow associated with each Interest and determines the subsequent direction for all incoming vehicles, Table II(b) illustrates a native FIB table maintained by the assistance node. The assistance node selects potential forwarders based on the information gathered from the IPT. The next destination indicated by the seg_id in the prefix name, where the node has the next destination equal to a specific direction, is selected as the eligible forwarder for that direction. Once an Interest packet arrives, assistance node satisfies his packet intermediately based on the FIB table. If the FIB contains multiple forwarders in a given direction, the assistance node may transmit to all these forwarders to increase the chance of successful transmission, serving the purpose of multipath forwarding if necessary.

D. Forwarding Strategy

On each road segment, the vehicle forwards Interest is as explained in Section II-B. Until the vehicle is within the transmission range of the assistance node, it leverages its current location (current segment) to determine the next junction ID and inserts this information into Receiver-VI field of the Interest packet, effectively creating an unicast packet. All Interests must be relayed through the assistance node to ensure that they are forwarded to the appropriate node that shares the same next destination, as indicated by the Interest. Consequently, Interests can be forwarded by vehicles from different vehicle flows that share the same next-destination.

TABLE II: Incoming Packet Table and FIB table

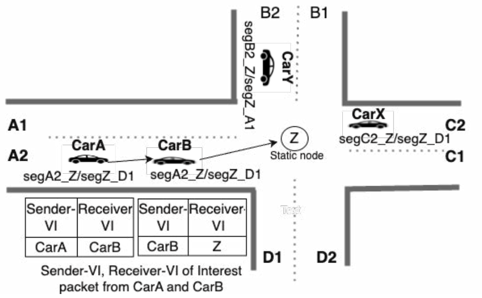
Source	Prefix
CarX	seg1_2/seg2_6/seg6_10
CarY	seg1_2/seg2_3/seg3_7

(a) Incoming Packet Table

Gateway	Next Hop
1	CarX
3	CarY

(b) FIB Table

For instance, in Fig. 4, the white node represents an assistance node placed at a junction. Vehicle CarA is part of the A1-Z-D1 flow, heading toward D1, and initiates an Interest packet with the prefix *segA2_Z/segZ_D1*. On road segment A2, the Interest packet is forwarded along the road, from CarA to CarB. CarA uses its camera to gather information about neighboring nodes and extracts Visual Identifiers (VIs) based on visual information, assigning them to these nodes. Among the surrounding nodes, CarB is selected as the candidate node, and CarA places its ID in the Sender-VI field, while CarB's ID enters the Receiver-VI field.



Sender-VI	Receiver VI	Sender-VI	Receiver-VI
CarA	CarB	CarB	Z

Sender-VI, Receiver-VI of Interest packet from CarA and CarB

Fig. 4: Interest forwarding along straight road to junction

Meanwhile, assistance node Z receives Interests from CarX and CarY, which have just moved past junctions C3 and B2 and possess Interests with prefixes *segC2_Z/segZ_D1* and *segB2_Z/segZ_A1*,respectively. Z checks the FIB, which is currently empty. Z updates CarX and CarY as gateways for D1 and A1, respectively. Following this update, when CarB enters the transmission range of the assistance node within the junction (200m), it sends an Interest packet to Z. This Interest packet contains CarB VI in the Sender-VI field and the ID of the assistance node corresponding to the known junction (Z) in the Receiver-VI field. Upon receiving the Interest packet from CarB, Z consults its FIB entries and recognizes that both Interests from CarX and CarB share the same next destination D1. Consequently, it forwards the Interest packet from CarB to CarX and adds CarB to FIB as an alternate candidate gateway for D1, alongside CarX. Z also acknowledges CarY as a new gateway for the vehicle flow heading toward A1 and updates its FIB table accordingly, as shown in Fig. 5.

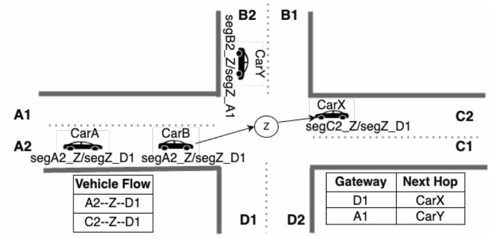


Fig. 5: assistance node processes the upcoming Interest

IV. PERFORMANCE EVALUATION

In this section, we devised a scenario to rigorously evaluate the performance and capabilities of our proposed system. The objectives of the presented results are to assess the following key aspects:

- Interest Packet Delivery Ratio.
- End-to-end delay: This ensures that it is suitable for supporting traffic information forecasting services.
- Average hop count: Measure the efficiency and cost of a network communication method

A. Scenario settings and evaluation methods

In our simulation, we used ndnSIM version 2.8 [11], a module based on the NS3 simulator that supports the NDN architecture. 4x4 grid map was generated using SUMO [12] as shown in Fig. 6. The number of vehicles in the simulation varied from 60 to 200, with initial locations randomly deployed, and vehicle velocities distributed within the maximum speed limit. All nodes communicated using Ad-hoc mode 802.11p, with a transmission range of 100 m, which is related to the range of the cameras used. The packet sending rate was set to 10 packets/s, and the simulation duration was 200 s. Additional simulation parameters are summarized in Table III

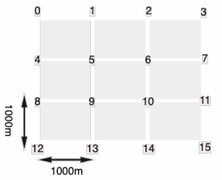


Fig. 6: 4x4 grid map

TABLE III: Simulation Parameters

Parameter	Detail
Network Simulator	ndnSIM 2.8
Mobility Generator	SUMO
Simulation area	3040 m x 3040 m
Number of vehicles	60 80 100 120 140 180 200
Number of assistance nodes	16
Maximum Velocity	35 m/s
Transmission range	100 m
Interest rate	10 packet/s
Beacon rate	1 packet/s
MAC protocol	802.11p
Simulation time	200 s

In this specific scenario, we pre-defined destinations for each vehicle, corresponding to distinct vehicle flows. Only the assistance node of junction 10 (node 10) as a Producer has a content of traffic jam occurred at exit 15, vehicles obtain this event only by Data from node 10 or when arriving at exit 15. Consequently, all vehicle flows heading toward exit 15 received Data packet returns, while the others served as intermediate nodes in the communication. We compare our proposed method with a pure V-NDN method [7] and a flat-forwarding based protocol called MMM-VNDN [8]. V-NDN is a position-based protocol that implements NDN in VANETs [13]. In V-NDN, nodes maintain their neighbor by periodically exchanging beacon messages. The selection of the next candidate forwarder is based on various metrics, such as link quality, distance, and other factors. On the other hand, the authors of MMM-VNDN propose a protocol that uses MAC addresses as node identifiers to create an unicast-based protocol. MAC addresses are added to both the Interest and Data packets to track the packet transmission. MMM-VNDN does not utilize location information, which can result in flat-forwarding, where all packets are forwarded in any direction.

B. Simulation Results

Fig. 7 illustrates the impact of the number of nodes on network performance in terms of the delivery ratio metric. All three methods exhibit a similar trend of increasing the delivery ratio as the number of nodes increases. As the number of vehicles increases, the network becomes denser, allowing nodes to reach candidate nodes more frequently and reduces transmission losses at the MAC layer. The results show that our proposed method achieves a delivery ratio more than 60%, compared with over 30% for V-NDN and 20% for MMM-VNDN. This indicates that the use of assistance nodes significantly benefits routing performance at junctions, resulting in a higher success rate for Interest packets being forwarded toward the Producer. MMM-VNDN, as a flat-forwarding method, experiences the highest packet loss because the Interest packets are distributed throughout the entire network. V-NDN performs better because of its use of position metrics in routing decisions. However, it still falls short in supporting on-demand routing based on a navigator, as packets continue to be sent across junctions in the wrong direction, away from the destination.

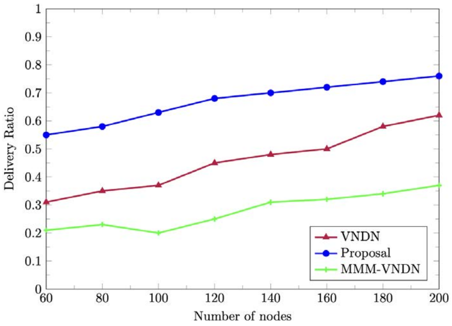


Fig. 7: Delivery Ratio

As shown in Fig. 8, when the number of nodes increases, all three schemes experiences a decrease the delay. Our proposal and V-NDN exhibit a gradual reduction in delay, with our proposal achieving a delay reduction of approximately 4 s, whereas V-NDN achieves a reduction of approximately 7 s. This improvement can be attributed to the efficient guidance of packet paths at junctions in the proposed protocol. In contrast, V-NDN does not differentiate between vehicle flows and is incapable of addressing packet forwarding across junctions (PFAJ), resulting in packet loss. On the other hand, MMM-VNDN consistently shows higher delays compared to the other methods, which is consistent with previous results, as it experiences the most packet losses owing to its flat-forwarding concept. Packets are forwarded in the wrong direction along the road, which requires additional time to reach their destination.

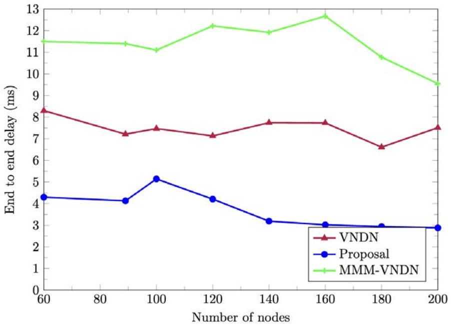


Fig. 8: End-to-end Delay

Fig. 9 shows the changes in the number of hops for each method as the number of vehicles increases. The results indicate that all three methods exhibit a proportional increase in the number of hops with network size. MMM-VNDN demonstrates significantly higher hop counts than the other methods, primarily because it lacks knowledge of the node positions. Our proposed method and V-NDN achieved equivalent results, with our method having a slight edge, and the gap widened as the number of nodes reached 160 and beyond. The reason for this difference is related to previous findings: assistance nodes help establish more efficient paths to junction 10 before reaching exit 15 than V-NDN, which only forwards packets directly to destination 15 and skips several packets that should be forwarded to the previous junction 10.

V. CONCLUSION

In conclusion, this paper introduced a novel visual-identification-based approach that employs hop-by-hop forwarding along a pre-defined road trip to monitor traffic conditions for safety applications. The design includes a hierarchical naming scheme in which each component corresponds to a traveled road segment, allowing efficient packet routing. Instead of including actual data in the packets, the scheme uses lightweight names to represent content, such as traffic jams or accidents. In addition, assistance nodes were deployed at each junction to facilitate packet routing according to the traveled path concept. These assistance nodes monitor incoming Interest packets to build their FIB tables, which include next-hop candidates for each segment.

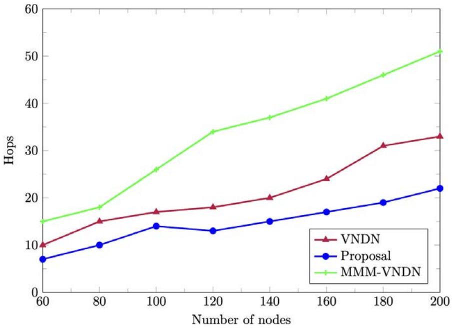


Fig. 9: Average hop count

The proposed approach outperformed previous methods in key metrics such as the delivery ratio, end-to-end delay, and hop count. Unlike flat-forwarding methods such as MMM-VNDN, which are ill-suited for highly dynamic topology networks such as VANETs owning to their high costs and inefficient route recovery, the proposed approach offers a more efficient unicast-based solution. It also outperformed the major V-NDN method, which relies on beacon messages and has drawbacks related to location-based forwarding.

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