A Novel Visual-Identification Based Forwarding Strategy for Vehicular Named Data Networking

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Abstract. In this paper we propose a robust and lightweight forwarding protocol in Vehicular ad hoc Named Data Networking (V-NDN). The concept of our forwarding protocol is that it adopts a visual-identification based approach where a vehicle would collect its neighbor list by camera to construct a hop-by-hop FIB-based forwarding strategy. Furthermore, due to the Face duplication on wireless environment, we add the visual information to Face to distinguish the incoming and outgoing Face that makes FIB and PIT in our design works more accurate and efficient. The result of performance evaluation focusing on the communication overhead shows that our proposal has better result in network traffic costs overall and also in Interest satisfaction ratio than that of the previous works.

Keywords: NDN for Vehicular Ad-hoc Networks (V-NDN) · Visual identification · Neighbor aware forwarding · FIB based forwarding

1 Introduction

Vehicular Ad Hoc Network (VANET) is a special mobility subclass of Mobile Ad Hoc Network (MANET). In VANETs, the infrastructure-less node moves and exchanges the information like accident, road construction, speed warning, traffic jams to provide safety and convenience to the drivers and passengers. Due to the highly mobile environments, while travelling with high speeds the connection links in VANETs is broken frequently and more challenge to maintain.

Named Data Networking (NDN) has been introduced as a promising technology to deal these problems above [1]. The motivation of NDN is shifting the information objects from host end-points (where) to name of the content (what). NDN uses two types of packets in all communications: Interest and Data. A consumer requesting a content sends an Interest packet containing the content name. A producer providing the corresponding content data returns a Data packet to the consumer. NDN routers transferring the Data packet cache the packet for future redistribution.

Originally, NDN is designed for wired network topology, it progressively be effectively applied to various wireless ad hoc network topology such as VANETs. The purpose of routing in NDN is how to construct Forwarding Information Base (FIB) for

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name prefixes, which specifies the correspondence between a name prefix and a face (or a neighbor identifier) to the content with this name prefix. However, in the case of wireless ad hoc network, node has only one wireless interface, it means no distinction between incoming and outgoing Face, FIB and PIT table become ineffective. Node have to flood all received Interest that causes broadcast storm. Furthermore, in such dynamic network routing protocol adapted to a highly dynamic environment such as VANETs, the end-to-end routing is costly and inefficiency that leads to almost current works approach to focus on hop-by-hop path and improve the next-hop selection method.

There are several approaches [2–5] has been proposed to solve these problems. N-Spray Wait [2] is a DTN based NDN forwarding by carry and forward Interest. Authors in [3] has a neighbor aware forwarding approach by not maintaining the FIB table and proposed a delay-based broadcast and next-hop selection depend on metrics such as distance, velocity. Besides, ADU [4] or MMM-VNDN [5] attempt to unicast-based by discover network on first phase by broadcasting, recover the function of FIB, PIT table for unicast forwarding by using host ID or MAC address instead of Face. These methods have some limitations, the first neighbor aware approach costs an overhead of control packet, Interest and also Data, the second is the accuracy of FIB based forwarding due to the mobility of nodes.

In this paper, we provide a new visual-identification based forwarding strategy that use neighbor aware approach to maintain FIB table as follows: We take advantage of equipped front rear cameras and propose a real-time next-hop selection based on visual-identification to provide an active neighbor discovery process rather than using control packet or flooding Interest, furthermore we also propose a concept of checking the available of candidate node before transmitting, it prevents a redundant path recovery phase and makes forwarding more flexible with high dynamic network. Our method is adopting two criterions: robust and lightweight. First, the goal of our deign is for supporting the driving assistance service, the Interest be used to request the information of road conditions ahead have to move forward as fast as possible that requires a robust forwarding method. "robust" in our term means despite of network topology changes, once look up the prefix on FIB table, appropriate entry is needed to exist constantly. The second criterion is lightweight, as we all know such kind of information has to updated periodically that causes network overhead, we want to design to minimize the traffic on network, thus possible to concede resources to other important safety information such as accident warning alert service.

The rest of this paper consists of the following sections. Section 2 introduces the related work on V-NDN. Section 3 explains the detailed our new protocol and Sect. 4 shows the performance evaluation focusing on the network overhead. Section 5 concludes this paper.

2 Related Work

2.1 NDN in Nutshell

In NDN the basic operation of a node on NDN is similar to an IP node. Once to request a content, node becomes a Consumer that initially creates an Interest packet including the name prefix of the content. When an intermediate node receives this Interest, the node checks three following tables in order:

- Content store (CS) table: Buffer memory which caches and retrieves contents.
- Forwarding Interest Base (FIB) table: A routing table which stores route of name corresponding to outgoing stream.
- Pending Interest Table (PIT): Not existed in IP based network, PIT stores information about unsatisfied (pending) Interest corresponding to incoming stream.

There will be three cases are considered. If the prefix in the Interest matches with data in CS, this node will become a Producer which return the corresponding content back to Consumer and discard the Interest. If any entry in PIT matches with an Interest, incoming interface (or called Face in NDN) is added into PIT and discard the Interest (same content request has already been forwarded). A NDN node uses information in the FIB table in order to send the Interest toward to Producer. If matched entry was found, Interest will be forwarded based on FIB table and node also records the prefix of Interest and the face which Interest arrives in PIT. If not (no match founded in the FIB table), the Interest will be discarded. Each PIT entry added can be used as the breadcrumb trail to send the data backs to the original Consumer.

2.2 Forwarding Strategies in NDN Based VANETs

The problem of duplicated Face and the mobility of topology that mentioned above is focused as the main challenge of V-NDN currently. A various of forwarding approach has been proposed, there are two approaches common be used are neighbor aware forwarding and FIB based forwarding. For instance, RUFS [6] periodic exchanges the recent satisfied list (RSL) to maintains a neighbor satisfied list (NSL) for the content discovery. Or in *N*-Spray Wait [2] is a DTN approach by using carry and forward mechanism, when node encounters, it passes the Interest to *N* nodes and these nodes carry Interest until obtain the Producer. These two methods are neighbor approach that ease the burden of maintaining FIB table by passing the Interest hop-by hop to increase the chance of reaching the Producer.

Reliable Forwarding Strategy (RFS) in [3] is NDN-based version of Greedy Perimeter Stateless Routing (GPSR). RFS has a typical neighbor aware forwarding approach which uses the beacon message to maintain neighbor list periodically. Beacon message contains Node ID, Position, Velocity, etc. On Forwarding Interest, node calculates the best metric neighbor as the next relay node. This hop-by-hop process repeats until Interest arrives to Producer. RFS uses PIT to return Data but do not maintain FIB due to the mobility of wireless network that costs amount of traffic pushed into network.

On the other hand, A Multi-hop and Multipath Routing (MMM-VNDN) [5] is a solution to deal with V-NDN by maintaining FIB and PIT table. MMM-VNDN has two main ideas are replacing Face by MAC address and broadcast-to-unicast switching mechanism. Overall, MMM-VNDN aim to recover V-NDN, makes it work correctly like the theory of NDN which originally supports for Wired Network. The duplicated face problem which mentioned above was solved by using MAC address instead of Face. The rest of MMM-VNDN works like wired-NDN when the Consumer floods the first

Interest to discover content, intermediate nodes update PIT and FIB and forward the Interest until arrives Producer. Data return by PIT and Consumer sends the following Interest with same content in unicast by using FIB table. Although MMM-VNDN is a full-function NDN model, it is not suitable for VANETs, once topology changes, it has to rebuild FIB by returning to flooding Interest phase.

3 Proposal

3.1 Overview

We have adopted the following design principles for our visual-identification based forwarding mechanism.

- To deal the Face problem of NDN on wireless environment and the control packet overhead as descried the above, we introduce a new Node Identifier called Visual Identifier (VI), VI is a result of a beaconless method based on visual recognition by taking the photos of running vehicles, VI helps node of NDN to divide the incoming Face and outgoing Face separately. We also maintain a neighbor table on each node individually that be used for forwarding purpose.
- We keep using FIB, PIT to take advantages of original NDN architecture about scalability problem, cache, content-centric data transmission and mobility. Aim to improve the capability of FIB and PIT, we replace the Face and Requester field by VI of node that help the hop-by-hop forwarding path easy to build and maintain. Through this way, we also eliminate the broadcast-based discovery phase of NDN by detecting a next-hop on the direction along the road via camera to create a new corresponding FIB entry in real-time.
- In path recovery aspect, we design a free-packet method called check before transmit, node uses camera to check the available of next-hop before sending packet, to prevent the broken link that trigger the broadcast mode, we recover that to unicast by replace the non-alive by the new one selected from VI table.

3.2 Visual-Identification and Packet Structures

The concept of visual-identification had implemented in various researches such as to identify and tag the malicious vehicles [15] or be used as a factor of authentication to improve the security issues [7]. Based on these benefits of using visual information, we have an idea to adopt it as metric on Interest forwarding protocol. We assume that all vehicles are equipped with front and rear cameras (drive recorders) which be used to capture the visual identifier of running around vehicles. Visual Identifier (VI) is the core of our design, the concept of VI is using high resolution camera to gather a combination of factors such as licenses plate number, color, brand, car type and others to identify and assign VI to each vehicle, VI is unique and is used as Vehicle Identifier.

On many previous researches, Node ID, MAC address, GPS position are used as Vehicle Identifier, the common disadvantage of all of them are the passive approach. It means the neighbor ID information have to “receive” from the outside passively. For instance, Node ID and Position are included in arrived hello packet or in other solution MAC address is added in Interest and Data packet. Thus, forwarding method based on such kind of Vehicle Identifier have some limitations on delay, packet overhead and accuracy. To encounter the above issues, our proposal focuses on VI as Vehicle Identifier to design a robust neighbor-maintaining method in the active approach. VI is not required any control packet to maintain, fetched via camera quickly and actively, VI also support unicast, multicast forwarding to prevent broadcast storm. Furthermore, VI is line-of-sight method, verify input of camera in real-time that overcoming the previous security issues of digital authentication using control massage.

Table 1 shows the parameters contained in VI table. Although the license number is unique that can become the VI (VI of Car A = 433-234), in some cases license plate number not able to captured (bad weather, obstacle or lack of light, etc.), for that reason we have additional fields such as color, brand, or any other identifies to improve the recognition ability.

The ability of this image processing is varied on specification of cameras on physical layer or the photo analyzing algorithm on application layer, hence we assume that the transmission range of wireless ad hoc network is equal to the range of cameras in our design to make sure line of sight node is always reachable.

Table 1. Visual identifier (VI) table

Visual identifier	License plate number	Color	Brand	Car type	Distance	Others
Car A	433-234	Black	Nissan	Sedan	50	Driver wears hat
Car B	342-567	Red	BMW	SUV	70	

We add three new fields into the Interest and Data packet. The detail of enhanced Interest and Data packet was summarized in Table 2.

Table 2. Parameters in interest and data packet

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

- Sender-VI: This field represents the VI of sender (The previous hop-by-hop forwarding sender).
- Receiver-VI: This field represents the VI of next-hop which was selected from VI table.

- Lifetime: Reduced by one before Interest is forwarded to next-hop, Interest is discarded when the lifetime count is equal to zero.

In our design, all the forwarding decision is based on FIB and PIT. An entry is created for an individual name prefix. The addition of VI concept to enhance the original FIB and PIT by switching Face into VI and also able to deal direction of vehicle in the forwarding rather previous works. Tables 3 and 4 show the forwarding parameter is the Node ID (VI) of upstream node in FIB and downstream node in PIT.

Table 3. Enchained forwarding information base (FIB).

Name	Next-hop
Check	Car B

Table 4. Enchained pending interest table (PIT).

Name	Requester
Check	Car A

3.3 Protocol Design

First Phase

Each vehicle takes the photos of running around vehicles and build up VI Table individually. The license number, car type, color, distance etc. are captured to identify the neighbor. To optimize the hop count metric, we decide the farthest in-range vehicle be selected as the candidate node for hop-by-hop forwarding purpose and be explained in the following step.

When a vehicle wants to monitor the road condition ahead for driving assistant service, it is considered as a Consumer and sends Interest. According to the design of NDN, at this point FIB is blank, the initial Interest has to be flooded into network to discover the content, or the Interest can be forwarded in unicast only if the Consumer maintains a neighbor list by beacon message [8]. For this reason, both of them costs in term of traffic overhead, we encounter this limitation by taking advantage of VI idea. Consumer selects the candidate node in VI Table which is closer to the Producer than itself and creates a new FIB entry with VI of next-hop at once. The initial Interest of this time contains Receiver-VI equals to selected next-hop and also Sender-VI equals to Consumer VI.

Once a relay node receives the initial Interest, it normally creates a PIT entry which correspond to the Consumer (extract the Sender-VI field on Interest). After that node selects the candidate node from VI table, create a new FIB entry, replace the current

Sender-VI by its VI and send the Interest in unicast as same as the original Consumer. The Lifetime of the Interest is reduced by one every time the Interest passes a node. This process repeats until the Lifetime equal to 0 or reaches the Producer.

In our scenario, due to the road-event discovering purpose, the Producer is the node that produces a road-event. In case Producer receives the Interest, Producer returns the Data to satisfy received Interest. The Data which also includes Sender-VI and Receiver-VI is sent back to the Consumer through the reverse path of the Interest which is previously maintained by PIT on intermediate nodes.

Second Phase

Node checks FIB entries to make the decision for the second Interest. In case route was found, node sends the Interest that corresponding to FIB entry, otherwise node acts like the first phase to transfer the Interest by VI table. This Interest is relayed until Lifetime becomes zero or arrives the Producers, the Data follows the PIT breadcrumb as mentioned in the first phase.

According to the goal of reducing redundant packet transmission, in the second phase we minimize the path from Consumer to Producer by forwarding the following Interest of same prefix based on FIB instead of using VI table. Selecting next-hop on VI table in this phase will raise the number of routes that points to the Producer and difficult to manage. Alternatively, we use VI concept to support path recovery function be explained in the following section.

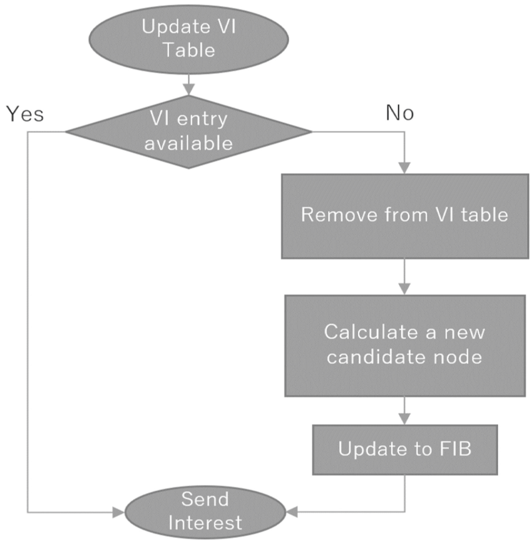


Fig. 1. Check before transmit mechanism

Path Recovery

As described in previous section, the characteristic of visual-identification process is in real-time, VI is captured by vehicle and added into VI table frequently. We have an idea to maintain and recover the route called "check before transmit mechanism", it can be displayed through the flowchart shown in Fig. 1.

Node examines the neighbor and VI table periodically, the VI of vehicle exits in VI table represents to the reachable node in real-time. Due to not using any protocol to populate the prefix, the next-hop of FIB field is updated based on VI Table entries. In our design, the vehicle comes in-sight of camera is considered as the good candidate node. For instance, one previous vehicle is become unable to visual recognize (not able to capture the number-plate or not enough factor to detect VI), it is considered as an unreachable node, node removes it from VI table. Node have to reactive the first phase to recreate a new path by calculating metrics to select a new candidate node, replaces the unreachable next-hop on FIB table by the new one and send the Interest. Comparing with previous researches the check before transmit mechanism reduces the amount of retransmission and route recovery packets.

An Example of Network Discovery in Our Method

From the second phase onwards, the forwarding protocol works based on FIB and PIT in a traditional way of NDN model. Thus, we explain the detail about a communication session between a set of Consumer/Producer in first phase or network discovery phase by the following example.

Figure 2 shows that vehicle A, it looks up entries in FIB table before sending the Interest. In-range of camera, vehicle A captures the number plates and other specifications of running ahead vehicle B and C, and puts B and C into its VI table.

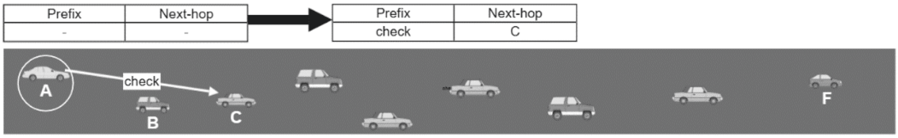
VI	License Number	Color	Brand	Car Type	Distance	Other
B	123-456	Green	BMW	SUV	30	
C	345-326	Blue	Toyota	Sedan	50	

Fig. 2. Vehicle A creates the VI table

In Fig. 3(a), at this time the FIB table of A is empty, A checks the VI Table to select vehicle C which has the best metric as the next-hop (the longest distance). A creates a new FIB entry for prefix "check" with forwarding candidate is vehicle C, puts its VI into Sender-VI and also VI of C into Receiver-VI field, send this Interest to C by unicast to retrieve the content as shown in Fig. 3b.

Figure 4 shows the forwarding when vehicle C receives the Interest, C inspects the CS. Thus, no corresponding data, C creates a new PIT entry respond to A. Similar to the previous implemented process on A, C also selects a next-hop for "check", adds a new FIB entry and send the Interest to D.

The intermediate node repeats this process sequentially to forward the Interest and update PIT simultaneously. Once the Interest reaches to area of vehicle F which has a warning of traffic jam ahead, vehicle F become Producer and terminate the Interest forwarding (Fig. 5).



(a) Vehicle A checks the FIB and create a new entry that points to vehicle C

Name	Sender-VI	Receiver-VI
check	A	C

(b) Vehicle A edits the Sender-VI and the Receiver-VI to send Interest.

Fig. 3. Vehicle A sends an initial interest.

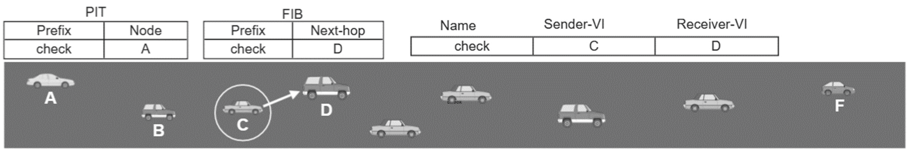


Fig. 4. Vehicle C repeats the previous process to forward the interest to vehicle D

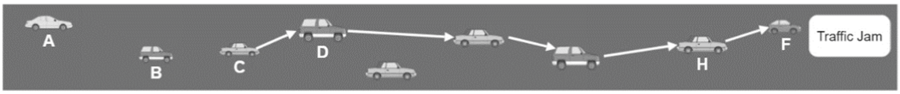


Fig. 5. Intermediate node relays the interest one by one until reaches to vehicle F which has a traffic jam information.

Figure 6 shows the return way of Data from vehicle F back to vehicle A through the path which is established by each intermedia nodes. F configures an appropriate set of Sender-VI and Receiver-VI and send back the Data to vehicle H. H continues to forward this Data to G and this process repeats until arrives to A.

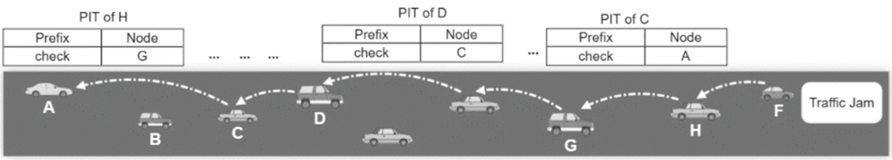


Fig. 6. Vehicle F return the data back to vehicle A

4 Performance Evaluation

4.1 Scenario Settings and Evaluated Methods

To evaluate the performance of our proposal, we used ndnSIM and SUMO to generate vehicle trace with the following parameters, are shown in Table 5.

Table 5. Simulation parameters

Parameters	Values
Simulation time	200 s
Number of vehicles	30, 40, 50
MAC protocol	802.11a 5 GHz
Transmission range	100 m
Velocity	30–40 km/h

We set up a long road topology has two lanes and one-way traffic. Number of vehicles varying from 30 to 50 in 2500 m area. Vehicles run along the road with minimum gap between car is 30 m and velocity is randomly distributed from 30 to 40 km/h. All the nodes communicate through ad hoc mode 802.11a with 100 m transmission range.

Our scenario is traffic prediction supporting service when a Consumer at the beginning of the road area periodic sends Interest along the road to update the traffic information ahead at 1 packet/second rate. A traffic jam event is occurred at the end of the road, the node in this area become Producer and respond all the satisfied Interest. In addition, during the simulation time we remove one intermediate node for one time to simulate the disconnected network and evaluate the path recovery function on each method.

Due to the goal of our proposal is reducing the redundant traffic, our evaluation focuses on the overhead of control packet, Interest packet transfer and total transmitted packet of relative nodes, we also measure the Interest Satisfaction Ratio (ISR) obtained from the total number of Data returned divided by the total Interest sent of Consumer to evaluate the accuracy of each method.

We evaluate the performance of our proposal compares to GPSR based NDN and MMM-VNDN protocol. The first one is GPSR, a typical IP-based VANETs which uses beacon message to maintain the neighbor list, we use the UdpFace class in ndnSIM to simulate GPSR [9] method under NDN layer, it was detailed explained in our previous research [10].

With MMM-VNDN, we change the default term of Face on ndnSIM to MAC address to identify the node. MAC address of neighbor is tracked in the flood phase and be sent by broadcast to unicast switching in second phase.

In case of our proposal, we assume that the VI table is already built up by captured images taken by camera. Following our design, we imitate a sequence of hop-hop forwarding based on VI table by pre-defining a path from Consumer to Producer. We can use this way to estimate packet overhead in our proposal.

4.2 Simulation Results

Control Packet Overhead: The number of control packets is proportional to the numbers of nodes and times, we can confirm the total beacon *SUM* of n nodes in t seconds with rate m packets/s by following formula:

$\mathrm{SUM} = n \times t \times m.$

Figure 7 plots the result of total control packet generated in 200 s simulation time with m = 1 then SUM is $n \times 200 \times 1$. Our proposal and MMM-VNDN method use FIB table for decision thus the control packet is zero.

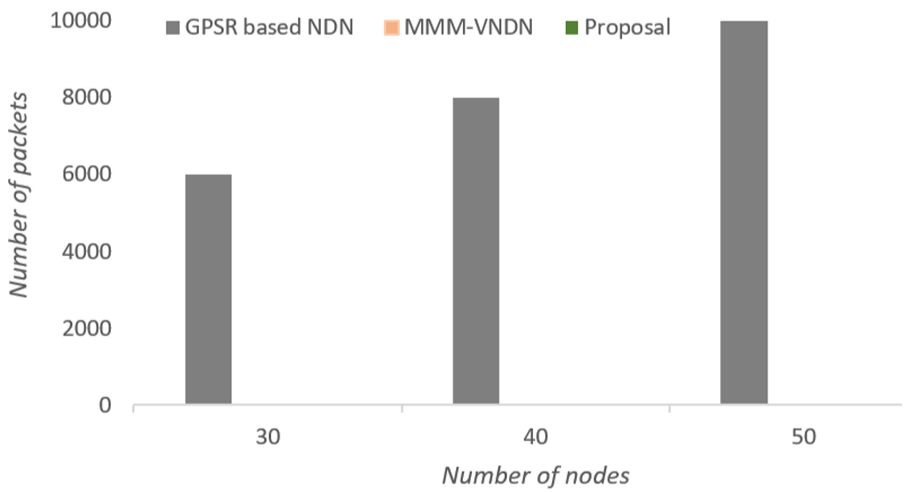


Fig. 7. Number of routing control packets

Interest Overhead: The total Interest includes the content discover Interest, recovery route Interest and retransmit time out Interest. In the same conditions, to prevent the redundant of Interest for the same content, we set Interest rate is 1 packet/s on our simulation. The result on Fig. 8 shows that MMM-VNDN is much higher than the others, the reason is MMM-VNDN has first flooding phase when Interest is rebroadcasted by all the nodes. Moreover, when the path to Producer was broken as explained in setting section above, MMM-VNDN costs retransmit packets and another flooding phase for route recovery.

GPSR based NDN and our proposal show the better result and consistent due to do not have any flooding phase, also in order using beacon and check before transmit mechanism to deal with broken link. We know that such pure FIB based forwarding method like MMM-VNDN suffers when the topology changes.

Total Transmitted Packets: Total transmitted packets are the total number of Interest, control packet and data packet are plotted in Fig. 9. In contrast to the previous good performance in the aspect of Interest overhead, GPSR based NDN generally sent highest traffic into network. The reason is GPSR based NDN method have to trade off a large

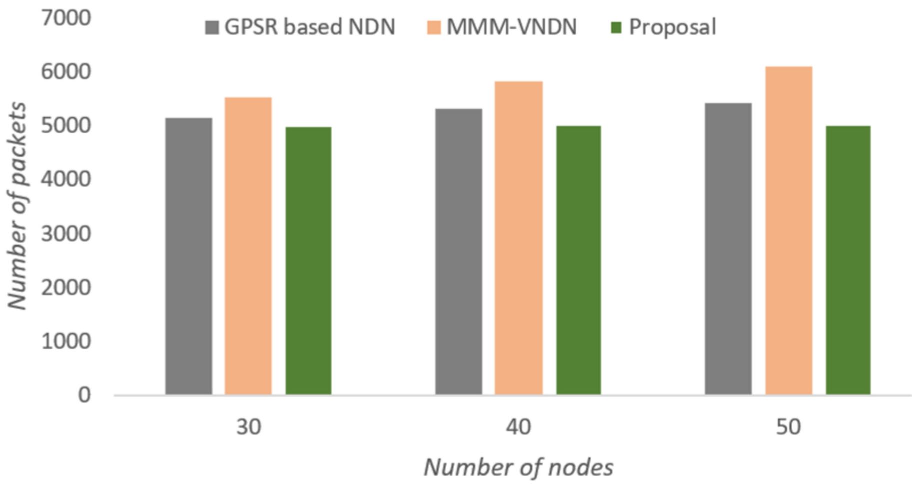


Fig. 8. Number of Interest packets

amount of control packet to keep network link always on (capable of sending an Interest to the next-hop immediately).

Although the number of Data packets increases with the number of Interest and the number of nodes (flooding phase), MMM-VNDN still have better result than GPSR based NDN because this method maintains a FIB table.

We can see that our method transmitted the less traffic to retrieve the content, according to the goal of design, it clearly shows the advantage in packet cost overall.

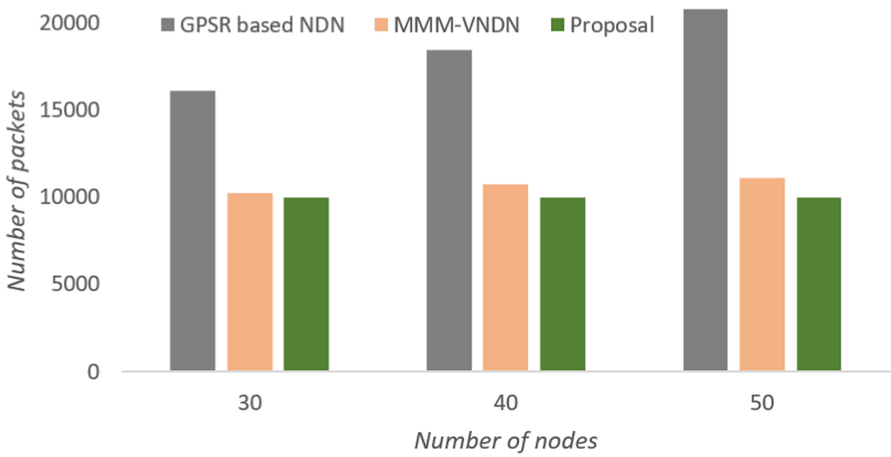


Fig. 9. Total transmitted packets

Interest Satisfaction Ratio (ISR): The result of ISR of three methods are plotted in Fig. 10. Although the GPSR based NDN and our proposal achieve similar values over

90%, our method shows better result with low overhead. This indicates that these two methods are suitable this kind of scenario. Due to the broken link setup, MMM-VNDN suffer an amount of Interest to resend and recover FIB entry that effect the result ISR above 80%.

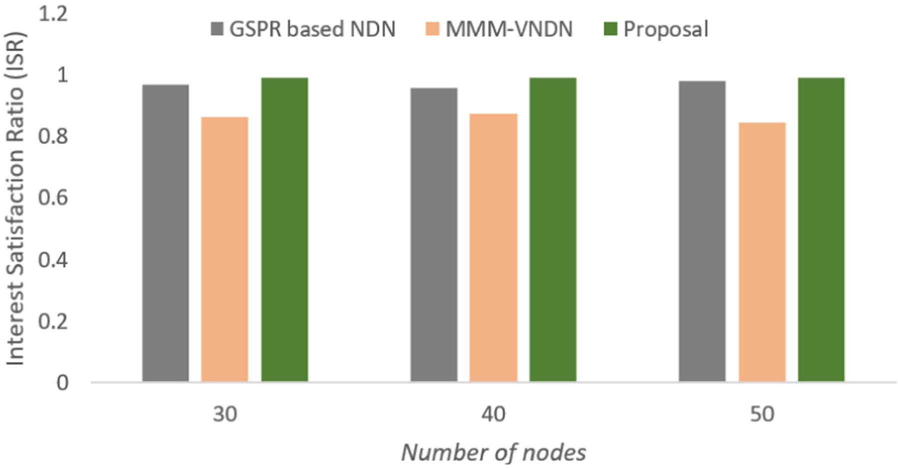


Fig. 10. Interest satisfaction ratio

5 Conclusions

In this paper, we proposed a new visual-identification based approach of Interest forwarding in Vehicular NDN network. Our proposal aimed at maintaining neighbors by taking advantage of front rear camera to capture the specification such as license number plate, color, car type, etc. of running around vehicles, then identify and assign the visual identifier (VI) to each node. We design to construct FIB table by adding visual information as metrics for a FIB selecting process. The visual-identification approach is an active way that reduce control packet into network compares to others beacon based methods. In addition, associating the idea of VI with forwarding based on FIB eliminates the first flooding phase in content discovery or in route recovery. The result showed that the proposed method requires the less amount of packet and in every aspect of overhead good delivery ratio than GPSR based NDN and MMM-VNDN.

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