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Using a Distributed Roadside Unit for the Data Dissemination Protocol in VANET With the Named Data Architecture

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ABSTRACT Vehicular ad hoc network (VANET) has recently become one of the highly active research areas for wireless networking. Since VANET is a multi-hop wireless network with very high mobility and intermittent connection lifetime, it is important to effectively handle the data dissemination issue in this rapidly changing environment. However, the existing TCP/IP implementation may not fit into such a highly dynamic environment because the nodes in the network must often perform rerouting due to their inconsistency of connectivity. In addition, the drivers in the vehicles may want to acquire some data, but they do not know the address/location of such data storage. Hence, the named data networking (NDN) approach may be more desirable here. The NDN architecture is proposed for the future Internet, which focuses on the delivering mechanism based on the message contents instead of relying on the host addresses of the data. In this paper, a new protocol named roadside unit (RSU) assisted of named data network (RA-NDN) is presented. The RSU can operate as a standalone node [standalone RSU (SA-RSU)]. One benefit of deploying SA-RSUs is the improved network connectivity. This study uses the NS3 and SUMO software packages for the network simulator and traffic simulator software, respectively, to verify the performance of the RA-NDN protocol. To reduce the latency under various vehicular densities, vehicular transmission ranges, and number of requesters, the proposed approach is compared with vehicular NDN via a real-world data set in the urban area of Sathorn road in Bangkok, Thailand. The simulation results show that the RA-NDN protocol improves the performance of ad hoc communications with the increase in data received ratio and throughput and the decrease in total dissemination time and traffic load.

INDEX TERMS Vehicular ad hoc network (VANET), named data network (NDN), vehicle to roadside unit (V2R), intelligent transport system (ITS).

I. INTRODUCTION

VANET, which is the wireless ad hoc communication between vehicles, has recently emerged as one of the hot topics in studies of wireless network technology. In particular, VANET is used in intelligent transportation systems or ITS. The ITS applications have become more influential in the current driving mode of road drivers. One of the prominent functions of ITS is to generate various types of helpful traffic information to drivers. The drivers can simply receive the surrounding traffic condition, road condition, safety information, commercial advertisement, etc. Moreover, VANET can help in traffic management. Tiaprasert *et al.* [1] and Comert [2] proposed a methodology to estimate the queue length by using VANET for traffic light control. In developed countries, VANET can collect information. For example, the vehicle information and communication system (VICS) [3] has been launched in Japan and particularly used to deliver traffic information to road vehicles. For the principle of VICS, all traffic information from road sensors is sent to a VICS central server and disseminated to vehicles on the road system. According to the VICS, a centralized data collection scheme has a great advantage on traffic information processing. However, there are a few disadvantages. First, the processes of both information gathering and disseminating between a central server and road sensors have long delays. Second, the accomplishment of the real-time applications is not smooth because of both lack of the central server and rapid mobility of vehicles. As a result, data dissemination methods become one of the challenging issues of VANET, which must be explored for some enhancements and improvements.

Several studies [4]–[7] focused on data dissemination on existing TCP/IP implementations for VANET. However, their data dissemination method cannot effectively work when the vehicle traffic density reaches low levels, which results in extreme packet losses. Furthermore, the IP address assignment of vehicles is required to maintain the path to route in highly dynamic environments. Therefore, the existing networks are unsuitable by those problems.

To achieve better performance, Arjunwadkar [8] explored an interesting idea of the name-data approach and compared the name-data approach with TCP/IP model of existing architecture. Named Data Networking (NDN) or Content Centric Networking (CCN) architecture [9] was recently proposed for the future Internet, which focuses on delivering the content that drivers want. The NDN uses two types of packets: "Interest" from a requester (i.e., question) and "Data" (i.e., answer) from a provider. The requester broadcasts an "Interest" message toward the potential providers. When the provider receives an "Interest" message and his/her data matches with the "Interest", the "Data" message is replied to the original requester using the same path that "Interest" message is forwarded. Since NDN nodes along the path contain the content, they can reply the cached content to requesters after they receive the same "Interest" message.

NDN deployment [10] has recently been extended to vehicular networking. NDN over VANET [11]–[18] is implemented. TalebiFard and Leung [11] used the network coding techniques of the content centric concept to improve data dissemination. Arnould *et al.* [12] implemented NDN principles in VANET with multiple radio interfaces to safety information dissemination. However, this proposal increases its complexity because the data dissemination is accomplished through the control of wireless medium, which is used by the packets with high traffic demand. Wang *et al.* [13] proposed vehicular hierarchical naming to analyze the benefit of the scheme for traffic data dissemination. Wang *et al.* [14] also proposed a data dissemination mechanism to reduce the latency of data delivery. This mechanism is set the timers to avoid collision of the NDN packet and alleviate the probability of losses. However, there is no advanced mechanism to prevent broadcast storm because the "Interest" packets are broadcast to other nodes in all directions. Ahmed *et al.* [15] proposed the neighboring vehicle is selected for Interest forwarding to prevent a broadcast storm. The best interest-forwarder selection cannot be identical to the direction of the content source. Yu *et al.* [16] applied opportunistic geo-routing based on NDN. Grassi *et al.* [17] and Bian *et al.* [18] also used geo-location in the "Interest" message. The algorithm can forward the "Interest" message toward the geo-location, where the content is generated. However, all of these NDN architectures for VANET establish data dissemination using a directly vehicular node, which frequently changes the route because of the vehicle mobility.

Moreover, NDN over the infrastructure-supported vehicular network [19]–[22] was designed. Wang *et al.* [19] focused on data collection, where the infrastructure type of RSU-supported VANET collects information from vehicles. Their work was compared with a host-centric concept based on the Mobile IP. Amadeo *et al.* [20] and Amadeo *et al.* [21] defined a preliminary CCN architecture, named CHANET [20], which constructs "Interest" and "Data packet" to forward by introducing new mechanisms to suffer unreliability of moving vehicles and wireless channel. They also designed an NDN architecture, which is called E-CHANET [21], for V2V and V2I on top of the IEEE 802.11 standard. The forwarding strategy had *A-Int*, *B-Int*, and *C-Obj* packets to advertise, discover, and transfer content packet. They explored the preliminary simulation results. The NDN implementation over infrastructure-supported V2V, named V-NDN, was proposed by Grassi *et al.* [22]. They modified NDN mechanisms and data structures to be applicable to vehicle movements. Using this method, the data received ratio was significantly increased, so the network traffic congestion was efficiently alleviated. However, there is no advanced mechanism to prevent broadcast storms because the "Interest" packets are broadcast to other nodes in all directions.

Nonetheless, this infrastructure-supported method did not provide any solutions to the traffic information dissemination problems. The traffic information must be inevitably processed and managed through the central server and returned to the disseminator. This process takes more time to relay a message from the central server. In conclusion, the issues of the latency and server bottleneck, which is caused by using the central server, have not been addressed in their work. Additionally, the cost of infrastructure-supported vehicular environments can be notably high.

Since VANET is generally sparsely connected and highly dynamic, it can affect the data dissemination among the vehicles to improve the quality of driving in terms of time, safety and distance. Existing studies on NDN over VANET mostly focus on infrastructure-supported communications. The studies provide some insight into the quality of communication when the standalone type of RSU or SA-RSU is deployed. However, more challenging scenarios for further investigation in vehicular mobility patterns are required when the SA-RSU is deployed. The motivation of our design is to make SA-RSU simple and easy to install. The system does not require heavy investment due to the minimum number of constructed road sensors into the centralized communication with little maintenance cost.

This paper is an extension from [7], which is a modification of the data dissemination protocol by using Named Data architecture. The contributions of the paper are as follows. We propose a new data dissemination protocol to assist the request packet to steer toward the direction of content producer. Then, this protocol modifies the format of the request packet and data packet, which contain geo-location information, and applies a timer-based forwarding decision

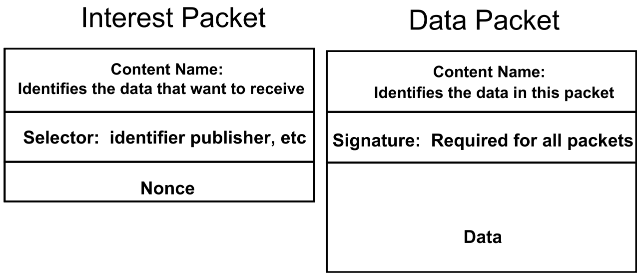
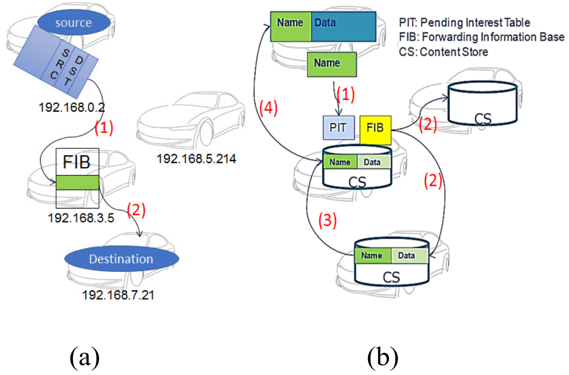


FIGURE 1. Packets in the NDN architecture.



(a) (b)

FIGURE 2. Concept of: (a) the existing network and (b) the named data network.

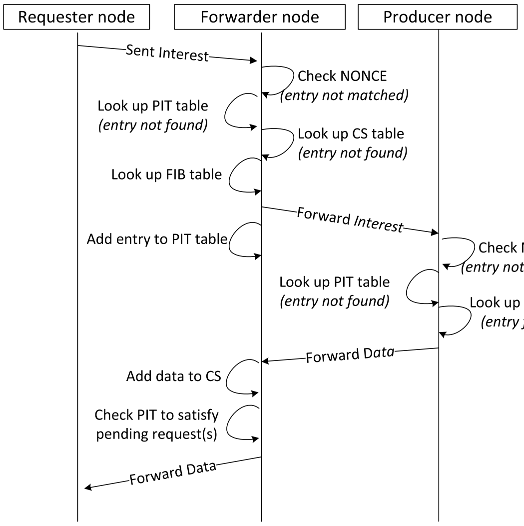


FIGURE 3. Diagram of basic operations in NDN.

mechanism to prevent the broadcast storm. To reduce the network traffic load for various vehicular densities, vehicular transmission ranges and numbers of requesters, we compare our proposed method, which is named Roadside Unit Assisted of Named Data Network or RA-NDN, with V-NDN [22] from a realistic network topology and using realistic driver behavior in the urban area of Sathorn road in Bangkok, Thailand.

The structure of the remainder of the paper is organized as follows. Section II explains the basic background of NDN. Section III proposes the RA-NDN protocol. Section IV presents the mathematical analysis. Section V presents the performance evaluation, results and discussion. Finally, Section VI summarizes the paper.

II. BASIC BACKGROUND ON NDN

Jacobson *et al.* [9] first publicly presented the Networking Named Content in 2006. The recent Named Data Networking (NDN) [10] project is an enhanced version of the Networking Named Content or Content Centric Network (CCN) architecture. The NDN proposes an evolution from the IP architecture (i.e., host-centric network architecture) to named data networking (i.e., data-centric network architecture). NDN maintains two packet types: “Interest” packet (question) and “Data” packet (answer) in Fig. 1.

A requester broadcasts an Interest packet to other nodes in its transmission range. The Interest packet can be forwarded through the network until the original content provider or any node, which stores a cached content, replies with the Data packet. In Fig. 2(a), the existing network uses the IP address to look up the IP address of destination. When a packet arrives, a node checks the IP header in the Forwarding Information Base (FIB), which maintains the IP destination, and subsequently forwards the packet to the designated destination node. Each NDN node has three important data components that it must maintain in Fig. 2(b):

i Pending Interest Table (PIT) keeps track of the names and incoming received Interest packets,
ii Forwarding Information Base (FIB) is a routing table, which maps the name components to interfaces, to relay Interests towards the content source (it differs from FIB in the existing network instead of IP),
iii Content Store (CS) caches the Data packet.

The NDN node follows the algorithm [23] (see Fig. 3):

- If it has an Interest packet that matches in NONCE list (which uniquely identifies each interest), it is dropped. Otherwise, it is checked in the Pending list in the PIT table.
- If the Interest packet is in the PIT, it is discarded. Otherwise, it searches in the CS table for a matching Interest. If it does not match with the Interest, it also checks in the FIB table for the forwarded Interest packet on the outgoing interface (for example, wireless channel), and the Interest is added in the PIT.
- If it has a Data packet that matches with the Interest in the CS, it replies with the Data packet on the same path as the Interest arrived.
- Before forwarding the Data packet, it is stored in the CS. Next, the Data packet is checked in the PIT to satisfy a pending request, and it is forwarded back to the original requester.

III. PROPOSED DATA DISSEMINATION PROTOCOL

This section presents the concept of the RA-NDN protocol in VANET with highly dynamic network topologies, short-lived and intermittent connectivity. To collect and process the traffic information, we deploy a standalone

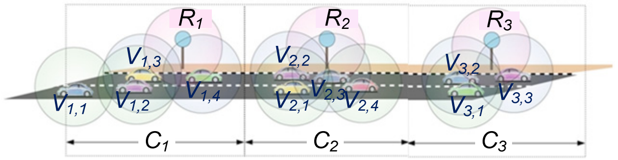


FIGURE 4. Concept of the RA-NDN protocol.

TABLE 1. Packet header structures.

Types \ packet	*Polling*	*Data*	*Request info.*	*Reply info.*
Name	Polling	Polling	Traffic	Traffic
Selector	Node_ Selector	RSU ID	RSU ID	Node_ Selector
Guilders	Conditions	Conditions	Conditions	Conditions
Position	Position	Position	Position	Position
Time-stamp	Time-stamp	Time-stamp	Time-stamp	Time-stamp
Signature	NONCE	Signature	NONCE	Signature

RSU (SA-RSU) as a communication node situated on the roadside, which is called the Roadside Unit Assisted of Named Data Network (RA-NDN). The SA-RSU works as a standalone node without connecting to any data-collecting or -processing center. The SA-RSU has the identical transmission range as deployed in vehicle-to-vehicle (V2V).

In Fig. 4, a road is divided into n cells, where C_n is denoted as cell index n, and each cell contains one SA-RSU. Let R_n be the SA-RSU in cell n and $V_{n,i}$ be the vehicle i in cell n. The vehicles obtain their locations from the device of the GPS. The proposed protocol consists of 4 types of messages extended from the NDN architecture:

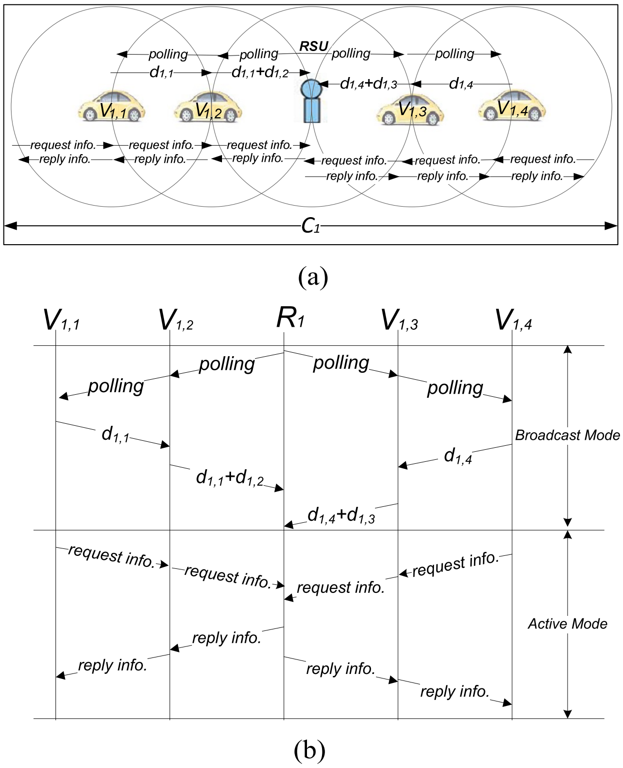
- A *polling message*: a periodically message from a SA-RSU broadcasts to all vehicles in the same cell.
- A *data* $d_{n,i}$ textitmessage: a message of $V_{n,i}$ in R_n is sent back to the SA-RSU after $V_{n,i}$ receives a *polling message*. The *data* $d_{n,i}$ contains the direction and velocity of vehicle i^{th}.
- A *request info. message*: a message of vehicle sends to its SA-RSU to request the traffic information of SA-RSU.
- A *reply info. message*: a message of SA-RSU replies vehicle after receiving the *request info. message.*

A. NAMING PATTERN

The packets add the source's position and roadside segment (RSU ID) to request the "Interest" message toward the direction of the desired data. The structure of *polling message* and *request info. message* are similar to the "Interest" message of the legacy NDN, and the structures of *data* $d_{n,i}$ *message* and *reply info. message* are also similar to the "Data" message of the legacy NDN. The structure of packets is provided in Table 1.

Each name prefix has a hierarchical name structure, and the "/" character represents a delimiter among different components. The naming design for *polling message*→ "/polling/node_selector/conditions/position/timestamp/NONCE" is as follows

- "Polling" identifies an application to make naming for the polling message.
- "Node selector" identifies a node of resource data when SA-RSU collects the traffic information in the road segment.
- "Conditions" identifies the details of the incidents such as identification, speed, lane and segment.
- "Position" identifies a position of the content source.
- "Timestamp" identifies the time that the event occurs.
- "NONCE" identifies each unique "Interest" message to prevent the loops in the network.



(a)

(b)

FIGURE 5. RA-NDN communication between the SA-RSU and the vehicles in the same cell; (a) SA-RSU communication with the transmission range of the vehicles; (b) diagram of the data dissemination protocol.

B. PROPOSED PROTOCOL PROCESS

The proposed process of a modified NDN protocol in VANET, which deploys SA-RSU and will be referred to as the RA-NDN protocol, is described. Each SA-RSU announces the name prefixes of the "Interest" message to report the traffic information. The proposed data dissemination protocol operation is divided into two modes: broadcast and active modes as shown in Fig. 5.

1) BROADCAST MODE

The protocol begins collecting data when each SA-RSU periodically broadcasts a *polling message*. We assume that the

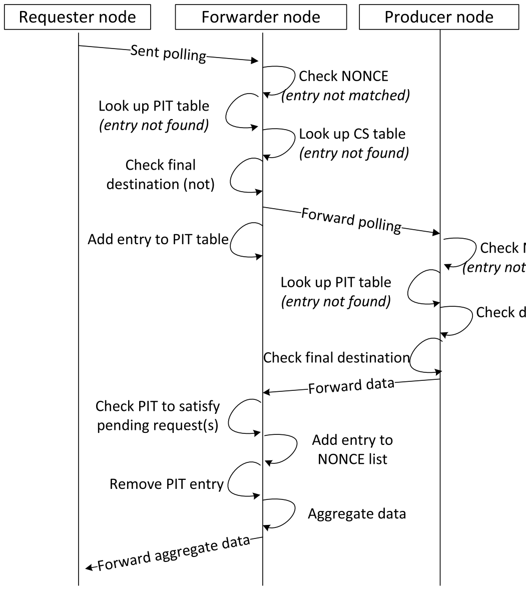


FIGURE 6. Diagram of the *polling message*.

data collection knows the structure of the name prefixes, which is the **/polling** prefix. Consider cell C_1 in Fig. 5, every node runs the following algorithm described in section II and adds the RSU ID header to check for vehicles in the cell of SA-RSU. As shown in Fig. 6., the requester node (or SA-RSU) sends the *polling message* to vehicles in its cell. Every vehicle who has received the *polling message* in the identical transmission range of SA-RSU will set the timer based on the distance away from SA-RSU, and the farthest vehicle will forward the *polling message* to the next hop of SA-RSU.

For example, suppose that vehicles $V_{1,2}$ and $V_{1,3}$ are in the border of the transmission range of roadside unit R_1. Let R_1 send a *polling messages* to every vehicle in its transmission range. $V_{1,2}$ and $V_{1,3}$ are the forwarder nodes, who will forward the received *polling message* to the other vehicles in the next hop. Then, $V_{1,1}$ and $V_{1,4}$ become the next forwarder nodes. Concurrently, $V_{1,2}$ and $V_{1,3}$ will wait for data $d_{1,1}$ and $d_{1,4}$ from vehicles $V_{1,1}$ and $V_{1,4}$, respectively. Until $V_{1,1}$ and $V_{1,4}$ cannot forward the *polling messages* to any vehicles, they will send $d_{1,1}$ and $d_{1,4}$ to the $V_{1,2}$ and $V_{1,3}$. When $V_{1,1}$ and $V_{1,4}$ send $d_{1,1}$ and $d_{1,4}$ to $V_{1,2}$ and $V_{1,3}$, $V_{1,2}$ and $V_{1,3}$ will include their data with the received data as $d_{1,1} + d_{1,2}$ and $d_{1,4} + d_{1,3}$, respectively, in a piggy-back pattern [24] before sending them back to R_1. The structure of data is shown in Fig. 7. Instead of being overwhelmed by data flooding all over the VANET system, the RA-NDN protocol lets only necessary data be sent and broadcasted in the system.

2) ACTIVE MODE

When a vehicle requires information from the SA-RSU, it sends a *request info. message*, which can be recognized by the **/traffic/RSU ID** prefix to an SA-RSU. In return, the SA-RSU will send a *reply info. message* to that requesting vehicle when the vehicle along the path does not store the *reply info. message*. The decision process executed in each vehicle is shown in Fig. 8. When the requester node sends the *request info. message,* the vehicles run the algorithm described in section II and add the checking distance. Every vehicle that receives the *request info. message* will set the timer relative to the distance away from the last hop vehicle. Among these vehicles, the farthest vehicle will forward the *request info. message* until the SA-RSU or any node that maintains a cached copy reply with the *reply info. message*.

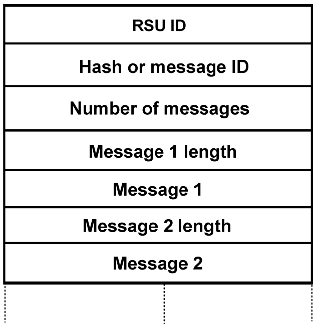


FIGURE 7. Structure of the *data* $d_{n,i}$ *message*.

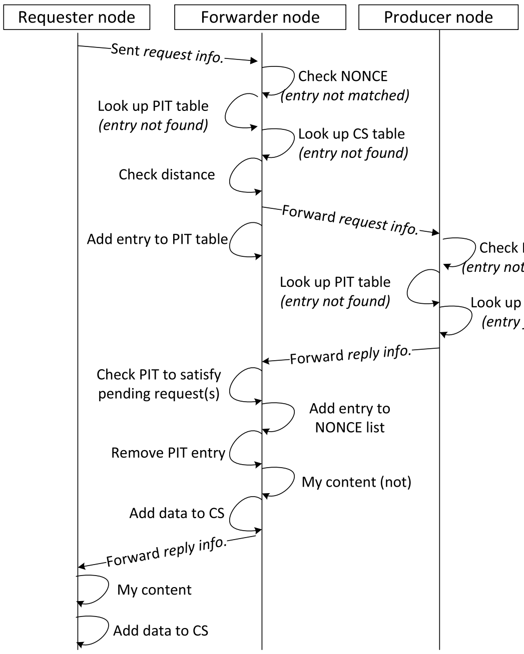


FIGURE 8. Diagram of the *request info. message*.

3) FORWARDING DECISION

Each vehicle performs the distance metric calculation for the *polling message* or *request info. message*. To make forwarding decisions, a timer-based mechanism similar to [16] and [18] is applied. The expiration timer is computed using (1).

$$T_{slot} = \left\lfloor \frac{R-d}{R} \right\rfloor \times (t_{\max} - t) + t \tag{1}$$

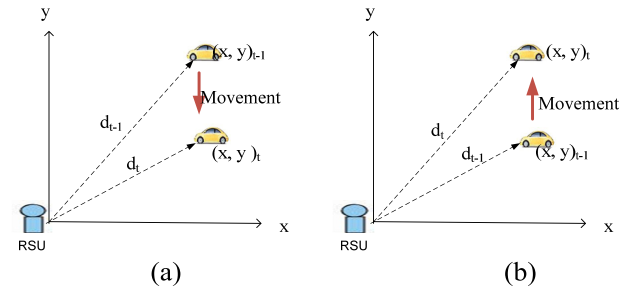


FIGURE 9. **Distance comparison: (a) Decreasing distance: the vehicles are heading toward the SA-RSU; (b) Increasing distance: the vehicles are leaving from the SA-RSU.**

T_{slots} is the expiration timer expressed as the number of time slots, which is identical to the slot length time in the MAC (Media Access Control) layer; R is the wireless transmission radius (m); d is the distance between its position and the position of the forwarder; t is the random timer (s); t_{max} is the maximum number of waiting time slots in the MAC layer.

The forwarder broadcasts the *polling message* or *request info. message* with its position to all vehicles in the transmission range. Then, the receivers calculate the distance between its position and the position of the forwarder. Then, the expiry time for all vehicles is calculated. As shown in Fig. 9, the vehicle heading toward SA-RSU will randomly set their expiration timer t within $[0, t_d]$ (Fig. 9(a)), whereas all other vehicles will set t to be larger than t_d (Fig. 9(b)). t_d is the threshold time of the distance comparison between vehicle and SA-RSU.

Therefore, the vehicle that is farther from the forwarder than other vehicles will wait with a shorter period than a nearby forwarder. In other words, T_{slots} is smaller when d is closer to R. When the timer expires, the vehicle rebroadcasts the *polling message* or *request info. message*. If other vehicles receive the same packet, they will discard the *polling message* or *request info. message* and stop the timer.

IV. MATHEMATICAL ANALYSIS

To demonstrate the performance of the RA-NDN protocol in VANET, the average round-trip time delay between a requester and a provider is presented. Let D_{rp} be the distance between a requester r and a provider p. If r and p cannot directly communicate, "Interest" packets and "Data" packets are sent via other nodes, which are called the "forwarder". Let R be the transmission radius of a vehicle. Therefore, D_{rp} is approximately equal to $i \times R$, where i is the minimum number of times (hops) that "Data" packets are sent via forwarders. To limit the length of the data dissemination relayed by SA-RSU, we set $i \leq N$, where N is the predefined maximum number of hops that a "Data" packet can be relayed from SA-RSU. When the "Data" packets are requested from SA-RSU, it can be found in a forwarder because the forwarder has requested the same data from SA-RSU earlier. The forwarder is called the "Data forwarder". Let r be the k^{th} requester and $n$be the distance between the requester and SA-RSU. Moreover, let the maximum distance between r and the SA-RSU be $n \times R$. Let $E_1(x,N,n,k)$ be the events that the distance between the requester r and the data forwarder is $x \times R$. $E_1(x,N,n,k)$ occurs when the furthest forwarder from SA-RSU of the first $(k{-}1)^{th}$ requesters is $(n{-}x) \times R$. Thus, the number of events in the data forwarder is the first $(k{-}1)^{th}$ requesters is $(k{-}1)$. The number of events that the first $(k{-}1)^{th}$ requesters except the data forwarder is not farther than $(n{-}x{-}1) \times R$ is equal to

$$\binom{n-x-1}{k-2}(k-2)!$$

The number of orders to the remain $N-k$ requesters is $(N-k)!$. Hence, the number of $E_1(x,N,n,k)$ is equal to

$$(k-1)\binom{n-x-1}{k-2}(k-2)!(N-k)!$$

Let $E_2(N,n,k)$ be the event that the distance between the requester r and the data forwarder is $i \times R$ where $i \leq N$. Therefore, the number of $E_2(N,n,k)$ is $(N\text{-}1)!$. Let $P(x|N,n,k)$ be the probability that the distance between the requester node r and the data forwarder is $x \times R$. Therefore, $P(x|N,n,k)$ can be determined as follows:

$$\begin{aligned} P(x|N,n,k) &= \frac{E_1(x,N,n,k)}{E_2(N,n,k)} \\ &= \frac{\binom{n-x-1}{k-2}(k-1)!\,(N-k)!}{(N-1)!} \\ &= \frac{\binom{n-x-1}{k-2}}{\binom{N-1}{k-1}}; \quad x =< n-k+1, \quad k =< N \end{aligned} \tag{2}$$

The probability of success when x is equal to 0, i.e., the vehicle has the data in its storage, is equal to

$$P(x=0|N,n,k) = 1 - \sum_{x=1}^{n-k+1} \frac{\binom{n-x-1}{k-2}}{\binom{N-1}{k-1}} \tag{3}$$

In Fig. 10, the x-axis of the graph is the distance between the requester and SA-RSU (n), and the y-axis of the graph is the probability of success (x=0) in (3). The results show that the probability of success decreases when n increases. Thus, the closest node may not request for the data packet because the farther node has requested and kept in its own storage according to the RA-NDN protocol concept.

The average is called the **R**equester-**P**rovider round trip time **D**elay or **RPD**, which is calculated as an expectation of $T(x)$ as shown in equation (4).

$$RPD = \sum_{x=0}^{n} P(x|N,n,k)\,T(x), \tag{4}$$

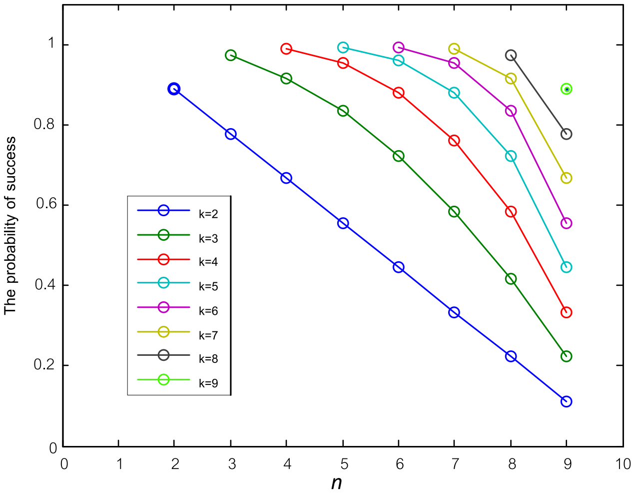


FIGURE 10. Probability of success in own node ($x = 0$).

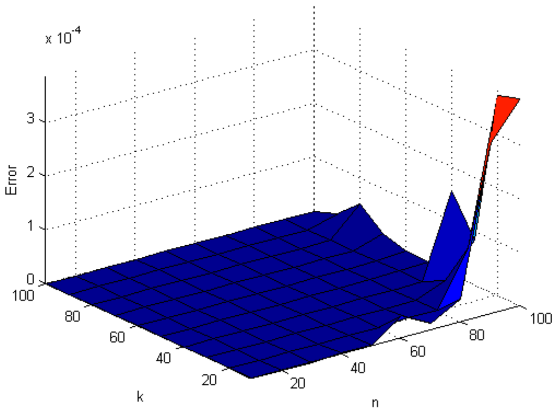


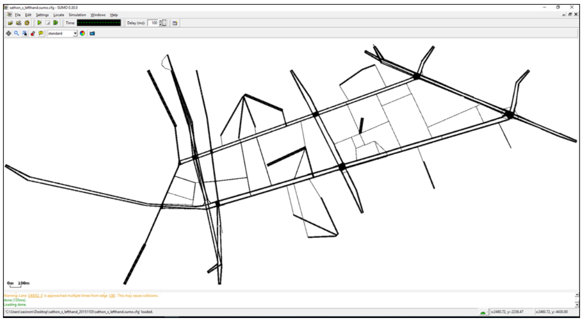
FIGURE 11. Absolute error of the derived $P(x|N, n, k)$.

where $T(x)$ is the round-trip time delay when the distance between the requester r and the data relay is $x \times R$. By simulating with equation (4) for 1 million times of Monti-Carlo simulation, Fig. 11 is obtained. The x-axis of the graph is n and varied from 10 to 100 positions; the y-axis of the graph is k and varied from 10 to 100 positions. The graph shows that the maximum error of (4) is 3.86×10^{-4}, which is usable in practice.

V. PERFORMANCE EVALUATION

All simulation experiments are performed over the NDN simulator for NS3, which is called ndnSIM [25]. The ndnSIM framework implements all features of the NDN architecture such as the naming scheme, "Interest" or "Data" packet format, caching and forwarding strategies. The node mobility scenarios are simulated by the microscopic traffic simulator SUMO [26], which calculates the movement of the vehicles according to a car-following model. This paper focuses on the data dissemination techniques. Therefore, physical or link layers use the standard IEEE 802.11p [27] for the performance evaluation.

(a)



(b)

FIGURE 12. Map of the Sathorn model project: (a) Sathorn area in the Google map; (b) Sathorn area in the SUMO.

TABLE 2. Saturation flow rates for all intersections [30].

Intersection		Maximum Number of Vehicles per Hour per Lane		
		Left	Straight	Right
Sathorn-Surasak	Sathorn Nuea	-	1692	-
	Sathorn Tai	1000	1428	-
	Surasak	1000	1212	1014
	Charoen Rat	1038	-	1278
Narinthorn		1000	1444	1146
Wireless		1000	1444	1146

A. REAL-TIME MOBILITY GENERATION

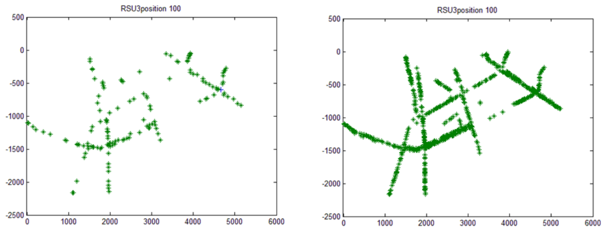
The WBCSD [28] or World Business Council for Sustainable Development launched the Sustainable Mobility Project 2.0 with 15 businesses and partners. Six cities are selected for the demonstration: Indore (India), Chengdu (China), Hamburg (Germany), Campeche (Brazil), Lisbon (Portugal) and Bangkok (Thailand). In Thailand, Sathorn district is selected as an experimental site, which is also known as the Sathorn Model project [29] in Fig. 12. It was selected as it is one of the critical Central Business District (CBD) areas with oversaturated traffic condition.

The saturation flow rate in Table 2 is the maximum number of vehicles per hour per lane on each direction period passing through an intersection.

A microscopic simulator SUMO is calibrated to Sathorn traffic based on actual traffic data from the Sathorn Model project on July 31, 2014 as shown in Fig. 12(b). The necessary

TABLE 3. Calibration between NETSTREAM and SUMO.

Parameter	Value
NETSTREAM	
Root mean square of travel time	9450.9 *s*/15 *min*
Root mean square error of flow	9856.2 *vehicles*/15 *min*
Mean travel time	0.33 *s*
Mean flow	0.82 *vehicles*
SUMO	
Maximum velocity	14 *m/s*
Acceleration	1.6 m/s^2
Latency	3.1 *s*
Minimum spacing between two cars	2.37 *m*



(a) (b)

FIGURE 13. Ratios of the Sathorn area (a) 2%, and (b) 10%.

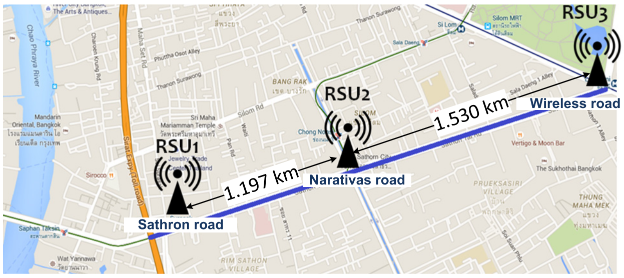


FIGURE 14. Position of each RSU.

calibration of SUMO parameters is performed by calibrating with the NETSTREAM traffic simulation program [31]. NETSREAM was developed and calibrated with actual traffic data by Toyota Central R&D Labs. The resultant calibrated parameters of SUMO are shown in Table 3.

B. SIMULATION SYSTEM

This section explains how we select parameters in the study. This is a snapshot of vehicles with ratios 2% and 10% of Sathorn area as shown in Fig. 13. The traffic demand observes at 15.30-17.30 on 31 July 2014.

Fig. 13 shows the position of each RSU at the intersection of Sathorn road (RSU1), Narativas road (RSU2) and Wireless road (RSU3), whose distances between RSU1 & RSU2 and RSU2 & RSU3 are 1.197 km and 1.530 km, respectively.

We assume that every vehicle is required to only be aware of the traffic information of its cell. If no RSU is deployed in the cell, each vehicle must directly communicate to the other vehicles. Otherwise, each vehicle will communicate with the SA-RSU based on the RA-NDN protocol as described in section III.

TABLE 4. Network simulation setup.

Parameter	Value
Simulation time (s)	10000
Number of simulations (times)	100
Physical/MAC protocols	IEEE802.11p
Transmission range (m)	200
CW Min/Max	31/1023
Data rate (Mb/s)	11
Payload (byte)	1024
Carrier frequency (GHz)	5.9
Maximum number of vehicles on Sathorn area	6410
The ratios of Sathorn area	0.2% - 10%
Maximum vehicle speed (*m/s*)	14
Propagation model	TwoRayGround
Antenna	Omni Direction
Payload (bytes)	256 512 1024 2048

The simulations were performed for the variable of real-time mobility generation with Sathorn model; the free-flow speed of vehicle is 14 m/s. The parameters for the network simulations, ndnSIM, are shown in Table 4.

C. PERFORMANCE METRICS

The performance is measured in terms of five metrics:

- Network traffic load (*TL*): total number of generated packets in the system (unit: packets)

$$TL = \sum_{i=1}^{N} S_i, \tag{5}$$

  where S_i is the number of generated packets of vehicle i, and N is the maximum number of vehicles.
- Data received ratio (*DRR*): ratio of the number of successfully received packets and the number of generated packets;

$$DRR = \frac{\sum_{i=1}^{N} D_i}{TL}, \tag{6}$$

  where D_i is the number of successfully received packets of vehicle i.
- Total dissemination time (*TDT*): total dissemination time of all packets that reach the provider divided by the data received ratio (unit: sec)

$$TDT = \frac{\bar{T}_f}{DRR}, \tag{7}$$

  where $\bar{T}_f$ is the average delay between the first "Interest" packet sent (which is the time of Interest retransmissions). A packet may be dropped and must be retransmitted before successfully reaching the end user.
- Dissemination time (*DT*): dissemination time of all packets that reach the provider divided by the data

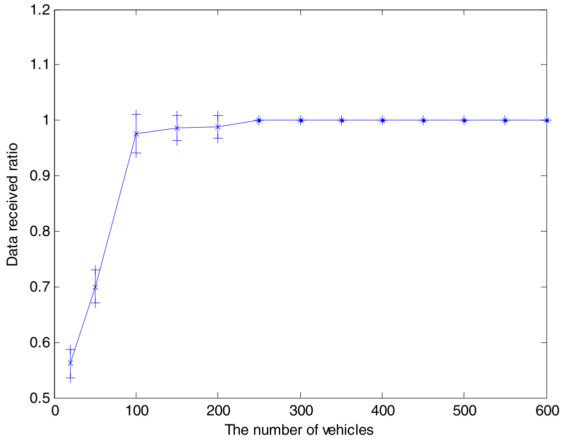


FIGURE 15. **Data received ratio.**

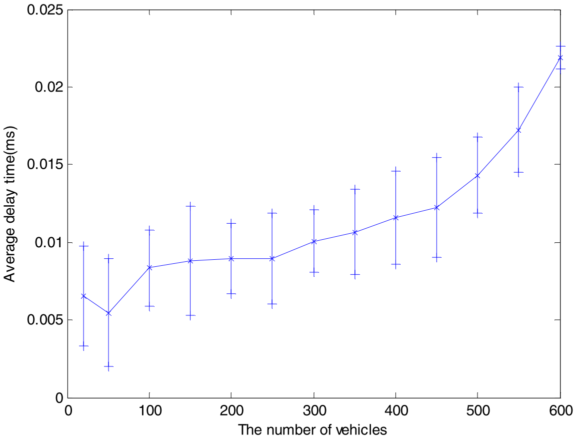


FIGURE 16. **Average delay time.**

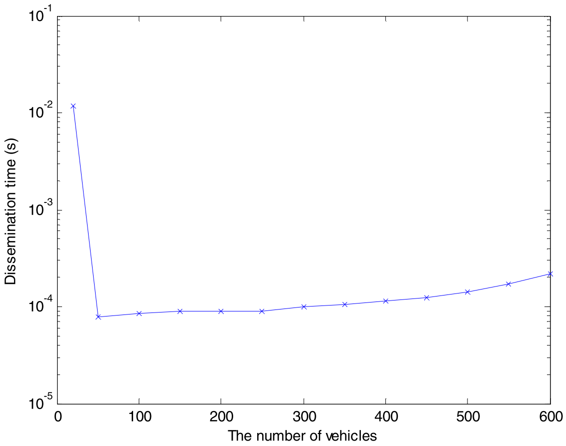


FIGURE 17. **Dissemination time.**

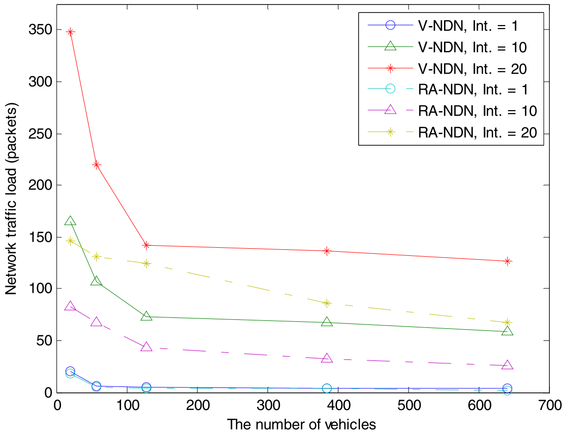


FIGURE 18. **Network traffic load.**

received ratio (unit: sec)

$$DT = \frac{\bar{T}_l}{DRR}, \tag{8}$$

where $\bar{T}_l$ is the average delay between the last "Interest" packet that was sent out.

- Throughput (TP): ratio of the total number of packets and the total dissemination time;

$$TP = \frac{PS \times \sum_{i=1}^{N} D_i}{TDT}, \tag{9}$$

where PS is the packet size (byte).

D. SIMULATION RESULTS

1) BROADCAST MODE

In Fig. 15, the result confirms the accuracy of data that the data received ratio with 95% confidence interval increases by approximately 55 - 100%. However, when the number of vehicles is approximately 20 or fewer, the data received ratio will obviously decrease because of the intermittent connectivity between the vehicles and the SA-RSUs.

Fig. 16 is the average delay with 95% confidence interval. When the number of vehicles increases, the average delay time is long because the vehicles receive the *polling messages* from the SA-RSU. All vehicles do not immediately return the *data messages*. After the vehicles receive the *polling messages*, they will set a timer before they forward the *polling messages* to other vehicles. Until the vehicles cannot forward the *polling messages* to any other vehicles, they will send the *data messages* back to the SA-RSU. Thus, the mechanism of the proposed protocol can reduce network traffic congestion in SA-RSUs.

The graph in Fig. 17 shows the optimal number of vehicles for the SA-RSU that collects the *data messages*. The dissemination time can be calculated from the average delay divided by the DRR. According to the result, the designed protocols achieve the highest performance when there are 50 vehicles on Sathorn road area.

2) ACTIVE MODE

a: EFFECT OF INTERFERENCE VEHICLES

This section examines the simulation results when the number of requester is 1, 10, and 20 times.

The parameters in the simulation are shown in Table 4. The reported result in Fig. 18 shows that the proposed protocol (RA-NDN) can reduce the network traffic load by

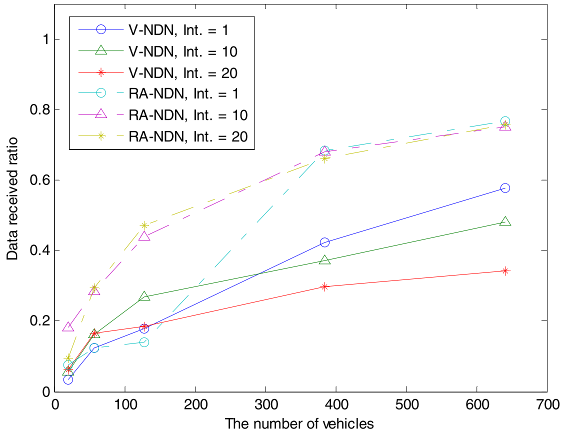


FIGURE 19. Data received ratio.

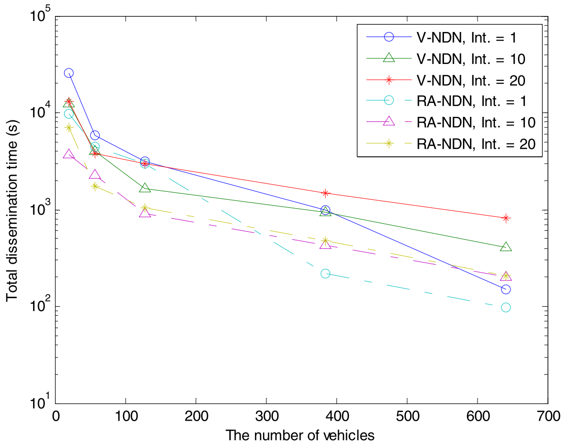


FIGURE 20. Total dissemination time.

approximately two times compared with the legacy vehicular named data network (V-NDN) [22]. The reason is that the position of the SA-RSU can steer the message forwarding direction to the requester instead of unnecessary flooding. Although the number of vehicles is increasing, the network traffic load will decrease because the network connectivity can improve the data exchange mechanism.

The accuracy of data is confirmed by the *DRR* as shown in Fig. 19. The highest ratio is found for the RA-NDN protocol because we assigned the RSU ID of Interest message and that message is guaranteed to reach the provider.

The results in Fig. 20 shows that the total dissemination time of the proposed protocol is lower than this legacy protocol. In a congested environment, a requester may face packet dropping and must perform retransmission before successfully sending back to the requester because the proposed protocol adds the position of the SA-RSU, which also assists in guiding to the appropriate direction, whereas another sends to all directions.

Fig. 21 is the result of the dissemination time of RA-NDN and V-NDN. As shown in Fig. 21, the dissemination time of RA-NDN is approximately 50 s, whereas V-NDN takes only 28 s to send one Interest packet in sparsely connected vehicles environment. This result occurs because we must calculate the timer-based forwarding value in the algorithm (see equation (1)), which causes a longer delay. Therefore, V-NDN forwards the packet without need for a timer calculation, which decreases the delay.

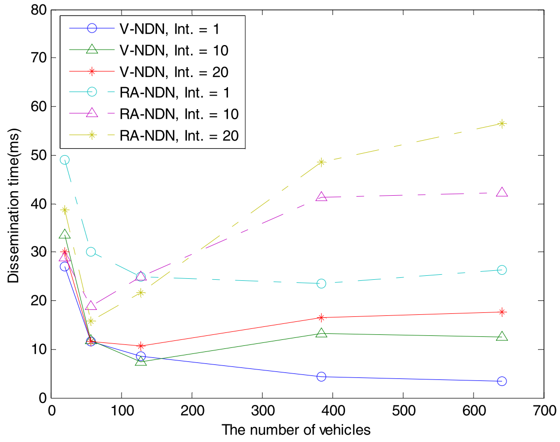


FIGURE 21. Dissemination time.

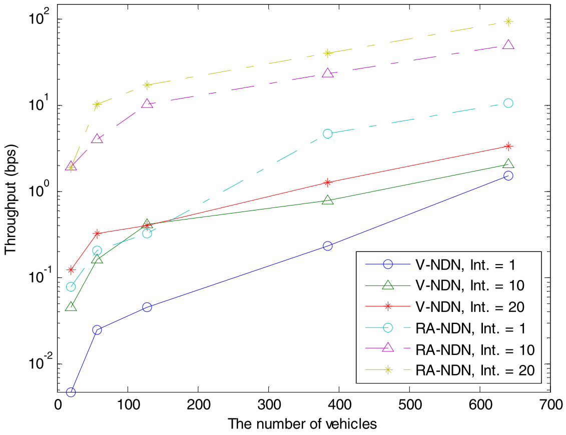


FIGURE 22. Throughput.

Fig. 22 illustrates the throughput of the system, where such measurements represents an overview on how the entire network functions. The maximum throughput is obtained when RA-NDN has sent 20 Interest messages. Surprisingly, RA-NDN achieves lower throughput when it sends only 1 Interest message, than the case of 20 Interest messages being sent. This is because the DDR of 20 Interest messages is higher than that of 1 Interest message. From the calculation in (9), the TDT is high, but the TP is low. Accordingly, the TDT of 20 Interest messages is longer than that of 1 Interest message. The results show that our proposed protocol reaches higher throughput. Since the SA-RSU is static and stable, our proposed protocol can significantly eliminate the effect on the frequent route because of the vehicle mobility.

b: EFFECT OF PACKET SIZE

The tests were run for the following packet sizes: 256, 512, 1024, and 2048 bytes. Comparing the RA-NDN and V-NDN protocols, we observe that a requester is 50 percent of vehicles on the road with network sizes of 128 and 1282 vehicles.

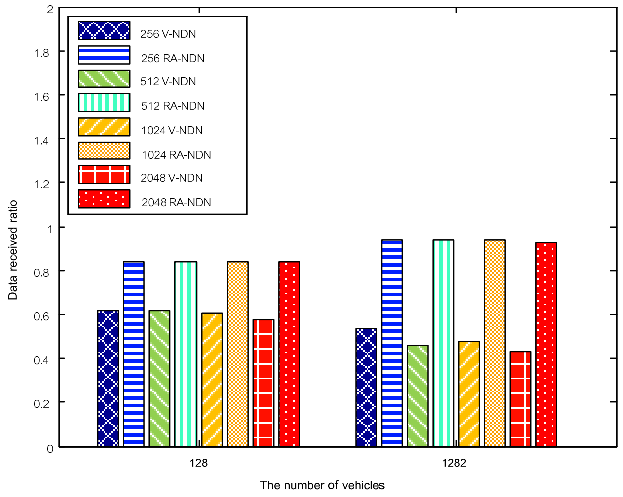


FIGURE 23. **Data received ratio.**

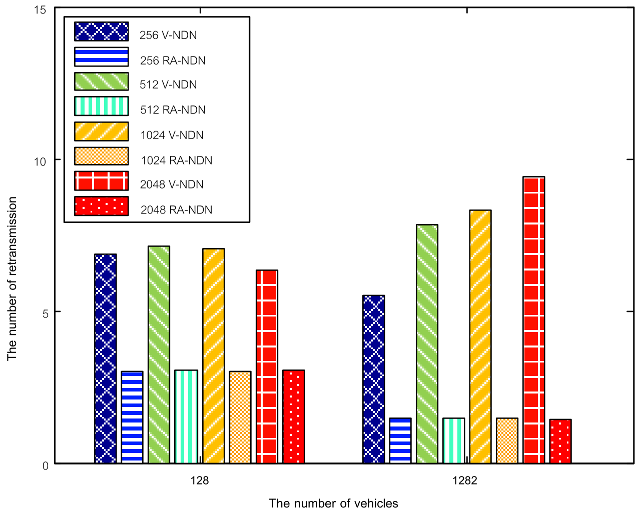


FIGURE 24. **Number of retransmissions.**

The performance of the proposed RA-NDN in terms of the data received ratio is discussed in Fig. 23. The DRR of V-NDN and RA-NDN is analyzed with network sizes of 128 and 1282 vehicles. For the network size of 128, the DRR of V-NDN and RA-NDN is approximately 60% and 80%, respectively. For the network size of 1282, the DRR of V-NDN and RA-NDN is approximately 60% and 100%, respectively, because the lower network size can result in more intermittent connectivity between the vehicles and the RSUs. This performance confirms that this proposed protocol enhances more reliable connection for vehicle communication.

Fig. 24 shows the number of retransmissions. The RA-NDN can reduce the retransmission by approximately three times compared with the V-NDN. When the network size is increasing, the retransmission decreases because the better network connectivity can improve the data dissemination mechanism. It is also possible to use the channel more efficiently and reduce the number of request messages that are generated in the system.

VI. CONCLUSION

In this paper, the proposed protocol is called the Roadside Unit Assisted of Named Data Network or RA-NDN. Each SA-RSU can individually operate without relying on a connection between them or a connection between the RSU and the data center. Deploying the SA-RSU can improve the network connectivity and data dissemination in mobile environments. A network simulator, NS3, and a microscopic simulator, SUMO, are selected as tests to verify the performance of the RA-NDN protocol. The proposed approach is compared with V-NDN via a realistic traffic environment in the urban area of Sathorn road in Bangkok, Thailand. The RA-NDN protocol can decrease the total dissemination time and traffic load while increasing the throughput and data received ratio of traffic information retrieval in the VANET environment.

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