Research Article

Comparison of Data Dissemination Protocols for Road Traffic Collecting Application in a Vehicular Ad hoc Network

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DOI: 10.14416/j.ijast.2017.08.001
Received: 14 February 2017; Accepted: 5 April 2017; Published online: 9 August 2017

Abstract
Providing real-time road traffic information to drivers is a critical step to improve road traffic efficiency by allowing appropriate routes to be chosen. In a Vehicular Ad hoc Network (VANET), a query message can be disseminated along several road paths for collecting road traffic information. While several VANET protocols have been proposed to accomplish such task, they were evaluated in different settings, environments, and a limited scale. To gain better insights for actual deployment, it is necessary to explore their relative performance advantages and limitations. In this paper, we compare Slotted 1-persistence, Efficient Directional Broadcast (EDB), Data dissemination pRotocol In VEhicular networks (DRIVE), and Road Traffic Collecting (RTC) protocols under a large scale city networks, high vehicle density, multiple query sessions, and the presence of interfering background traffic. The evaluation focuses on the average percentage of targeted road segment coverage, the total number of transmitted messages, and the completion delay time. The results show that EDB outperforms other protocols in terms of the road segment coverage with highest number of transmitted messages while RTC yields a lower number of transmitted messages with less road segment coverage. However, EDB requires road-side units at every intersection and its performance dramatically drops under the failure of road-side units.

Keywords: Vehicular Ad hoc Network, Query dissemination, Collecting road traffic information

1 Introduction

To collect road traffic information, currently, various kinds of fixed traffic sensors or fixed infrastructure such as inductive loop and electromagnetic detection system [1], [2] are installed on roads. The information is also collected by estimating the movement speed from location data in on-board mobile phones. Without any requirement like fixed traffic sensors, infrastructure, or mobile phone, a Vehicular Ad hoc Network (VANET) can be used to collect road traffic information. VANET is a class of mobile ad hoc network formed by vehicles on the road. Unique characteristics in a VANET are high and correlated node mobility, large geographical scale coverage, and irregularities of the node density and the signal propagation environment due to obstacles in the road and city infrastructure.

This paper considers a VANET application where a source node disseminates a query message over predefined routes to a specific destination location to retrieve the road traffic information. To do so, many

Please cite this article as: S. Wongdeethai, P. Siripongwutikorn, and K. Gyoda, "Comparison of data dissemination protocols for road traffic collecting application in a vehicular ad hoc network," *KMUTNB Int J Appl Sci Technol*, vol. 10, no. 3, pp. 177–189, Jul.–Sep. 2017.

data dissemination protocols to spread a query message are applicable. Data dissemination protocols in a VANET can be classified into broadcasting protocol and geocasting protocol. A broadcasting protocol is designed to spread an information to all other nodes. Most VANET broadcasting protocols aim to reduce the number of transmitted messages by allowing only the farthest neighbor to rebroadcast a message [3]–[13]. A geocasting protocol is similar to broadcasting protocols except that it defines forwarding vehicles and a set of target vehicles by using road areas [14]–[18].

The existing protocols can be classified into 2 major mechanisms, which are probability-based and delay-based mechanism. The probability-based approach determines the forwarding probability from node density [6], [11], node speed [8], [12], or distance from a sender [10]. However, the probability-based has some limitations. For example, a message may not be disseminated if the nodes are assigned very low rebroadcast probability under a high node density or they move at very low speed due to traffic congestion. Conversely, there is a high message redundancy in a sparse network or nodes move in a free-flow manner.

The delay-based mechanism aims to select the farthest neighbor as a next hop to forward data. To do so, the delay time before retransmitting a message is made inversely proportional to the distance from the sender so that the farthest neighbor would the one to retransmit. Examples of protocols using a delay-based mechanism include Slotted 1-persistence [10], Efficient Directional Broadcast (EDB) [9], Data dissemination pRotocol In VEhicular networks (DRIVE) [17] and Road Traffic Collecting (RTC) [18]. While the above mentioned protocols can be adopted in road traffic collecting applications, deciding which one is most effective to deploy is inconclusive. The reason is that their relative performance in a realistic network environment is unknown due to the fact they were evaluated in different topologies, parameter settings, and scales. For example, Slotted 1-persistence was simulated under a single query session and 10 km of straight road environment. EDB was simulated under a low node density and a small network environment with multiple query sessions while DRIVE was simulated under a single query session and high node density on a small network with a very short road segment.

The aims of this research is to evaluate the performance of delay-based data dissemination protocols under more realistic and extreme network environments than the existing works. Effects of factors including the node density, the number of parallel query sessions, and the presence of background traffic are explored in a large network with intersections and vehicle mobility. The results would give more insights on performance advantages and limitations of these protocols and how they should be appropriately deployed in a real situation.

The rest of the paper is organized as follows. Section 2 provides the detail of selected data dissemination protocols and explains how they are modified to work under city environments and multiple query sessions. The simulation methodology for comparative performance evaluation of those protocols is presented in Section 3. The experiment results are discussed in Section 4 and the conclusion is given in Section 5.

2 Data Dissemination Protocols Studied

In this section, we summarize the operation of Slotted 1-persistence, EDB, DRIVE, and RTC protocols studied in simulations. In our performance evaluation, these protocols are largely implemented based on their specification. However, we need to extend some aspects of these protocols in the lack of sufficient detail or incomplete specifications in certain simulation scenarios. The modification details are presented along with individual protocols.

2.1 *Slotted 1-persistence*

Slotted 1-persistence is designed to disseminate a message on highways by using the distance-slot based forwarding mechanism. A transmission range is chunked into slots and the slot order is assigned based on the distance from the current forwarding node. The node located in the farthest slot has the best chance to be promoted as the next forwarding node.

2.1.1 Basic mechanism

Upon receiving a message, each neighbor waits for a period of *WAIT_TIME* + T_w. If no duplicate message has been received within that period, it will rebroadcast the message. The parameter *WAIT_TIME* is a constant value and T_w is calculated as

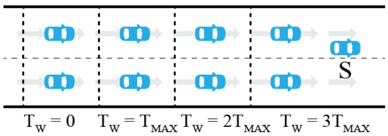


Figure 1: Basic mechanism of Slotted 1-persistence protocol.

$$T_w = \left[N_S \times (1 - \frac{d}{R}) \right] \times T_{\max} \quad (1)$$

where N_s is the predetermined number of slots, d is the distance from the closet forwarding node, R is the transmission range, and $T_{\max}$ is maximum waiting time for neighbor response. For example, in Figure 1, the transmission range is divided into four slots. The node located in the farthest slot will be assigned a shorter waiting time.

2.1.2 Implementation decisions

Slotted 1-persistence is also designed for propagating messages only on a straight road. To make it propagate message over an intersection, we modify the protocol by make the neighbors in each road segment at an intersection rebroadcast the message. The neighbors who wait for T_w will cancel the waiting status if they receive a duplicate message only from the same road segment. The duplicate is ignored.

2.2 *EDB*

To allow a message to be disseminated over an intersection, EDB requires a Road Side Unit (RSU) at every intersection. An RSU is assumed to have multi-directional antennas with 30° beamwidth pointing to each road segment outward from the intersection. Nodes in EDB are also equipped with the same 30° directional antenna in both forward and backward directions. The packet is forwarded to the direction opposite to the one the packet has arrived. Each neighbor computes the waiting time by observing its own position and the sender's position. EDB uses acknowledgment message to prevent rebroadcast duplicate messages. The sender repeats broadcasting the message if the disconnected path is detected. The message rebroadcast is repeated until a new neighbor is detected.

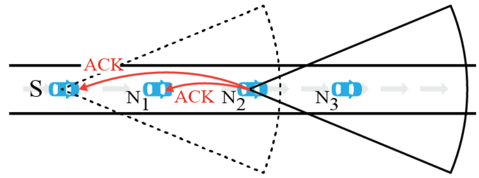


Figure 2: Basic mechanism of EDB protocol.

2.2.1 Basic mechanism

Initially, as shown in Figure 2, source node (S) starts broadcasting a message and waits for response from its neighbors (N_1 and N_2). If there is no response within a timeout period $T_{\max}$, S will rebroadcast every $10 \times T_{\max}$ until it gets a response. When N_1 and N_2 receive the broadcast data, they will wait for time T_w before sending a response. The waiting time T_w is computed by using a simple distance based function as below

$$T_w = (1 - \frac{d}{R}) \times T_{\max} \quad (2)$$

where $T_{\max}$ is the maximum waiting time for neighbor response, d is the distance from the current forwarding node, and R is the transmission range.

N_2, which is the farthest neighbor, broadcasts the acknowledgment by using the same antenna that picked up the message. After N_2 broadcasts the response, the message will be instantly broadcasted by using the other antenna in the opposite direction. Other neighbors that receive the response will stop their waiting and return to an idle state.

To disseminate a message over an intersection, RSU is equipped with four directional antennas. At RSU, the message is always immediately forwarded to the road segment on the left-side and the right-side of the current road segments without sending any response to the sender. A node on the straight road segment will receive a message directly from the current forwarding node. An RSU keeps the message ID for a certain time period and every message is rebroadcasted only once.

2.2.2 Implementation decisions

Because most simulation tools available now do not support directional antenna, this protocol is modified to using an omni antenna rather than the directional antennas. In the dissemination process, a message will be forwarded in the forward direction. With a directional antenna, the downstream node will not receive the message that is sent to the leading node. Thus, the downstream node will not rebroadcast a duplicate message. However, when using an omni antenna, the downstream node will receive the message that is sent to the leading node and it will rebroadcast a duplicate message. Thus, EDB is modified to store the message session id in a list and it will check the list when a message has been received. If there is the message session id in the list, this message will be ignored. The area of interest concept is also applied to EDB. So, a message will be disseminated only on the selected road segment.

The RSU is also modified to rebroadcast a message to all connected road segments except the current road segment and use the message from RSU as an acknowledgment for the current forwarding node. Therefore, the current forwarding node will cancel rebroadcasting after receiving the acknowledgment from RSU.

By using two directional antennas, the neighbors which locate in an opposite side of each antenna that broadcasts a response will not be interfered with this response message. However, EDB with omni antenna experiences interfering responses. EDB broadcasts the data message to find a new rebroadcast node instantly after the response is broadcasted. In case that there are two neighbors having very close waiting time, the first neighbor will broadcast the response and the data accordingly like the second neighbor. Next step neighbors, which are neighbors of the first and the second neighbor, will initiate the waiting process after receiving the data message from the first neighbor, and then they cancel the waiting process by the response from the second neighbor. To handle this problem, the following condition will be applied: If the neighbors receive a response of the same session that they are waiting for and the response comes from a node in front of them, they will stop waiting and return to an idle state.

2.3 *DRIVE*

DRIVE is designed to disseminate a data within an area of interest. DRIVE uses the distance based mechanism to divide transmission into high priority area and low priority area. The high priority area is called the sweet spot, which is defined as an area of 45 degree line of sight for each direction (north, east, west, and south). The neighbors that locate in the sweet spot will be selected as a next forwarding node based on its distance from the sender. If there is no neighbor in the sweet spot, one of the neighbors in the low priority area will be selected as a next forwarding node.

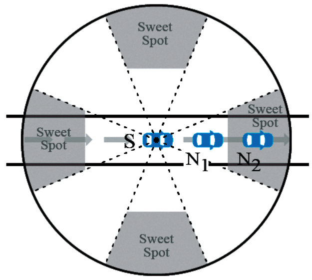


Figure 3: Basic mechanism of DRIVE protocol.

2.3.1 Basic mechanism

The sweet spot is illustrated in Figure 3. When N_1 and N_2 receive a message from node S and the message is received for the first time, they will compute their waiting time *T* depending on the area that they locate. If there is no duplicate message before the waiting time *T* expires, the message will be rebroadcast. Each neighbor determines that it is in the sweet spot by using the sender location in the received message and its own location to calculate the distance and the degree angle from the sender.

The waiting time *T* depends on the area of neighbors. *T* can be separated into 2 functions:

$$T_{pri\_1} = 0.01 \times \frac{d}{R} + rand(0, 0.01) \quad (3)$$

and

$$T_{pri\_2} = 0.01 \times \frac{d}{R} + rand(0.02, 0.05) \quad (4)$$

where T_{pri_1} is waiting for neighbors in sweet spot and T_{pri_2} is waiting time for neighbors outside sweet spot, *d* is the distance to the current node and *R* is the transmission range.

2.3.2 Implementation decisions

DRIVE is designed to select the farthest neighbor to be the next broadcasting node. From the waiting time Equations (3) and (4), the closest neighbor in the sweet spot will respond first. Thus, the propagation per hop will have a small progress. However, in [17] it is clearly indicated that the farthest node should be the next rebroadcast node. So, to make the farthest neighbor respond first, the waiting time equation for neighbors in the sweet spot is modified to

$$T_{pri\_1} = 0.01 \times (1 - \frac{d}{R}) + rand(0, 0.01) \quad (5)$$

and the one for neighbors outside the sweet spot is

$$T_{pri\_2} = 0.01 \times (1 - \frac{d}{R}) + rand(0.02, 0.05) \quad (6)$$

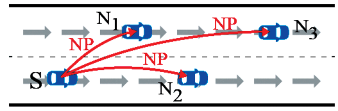
With Equations (5) and (6), T_{pri_1} and T_{pri_2} are inversely proportional to the distance between neighbors and the sender.

2.4 *RTC*

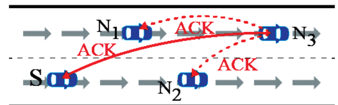
RTC protocol is designed to collect road traffic information on an area of interest. RTC is essentially a combination of both broadcasting protocol and geocasting protocol. It uses a broadcasting mechanism to disseminate a message and limits participating nodes by using its geographic location. A query message dissemination is based on most-forward-routing strategy that depends on the distance from the current forwarding. RTC also uses unicasting to send an acknowledgment and a Traffic Collecting (TC) message.

2.4.1 Basic mechanism

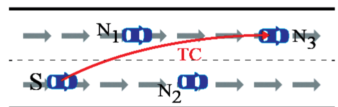
When a source node needs a road traffic information between itself and a destination location, it selects several shortest paths as Zone of Query (ZoQ). Then, it broadcasts the Neighbor Probing (NP) message and waits for acknowledgment from its neighbors. If there is no acknowledgment within the timeout period T_{np}, the current forwarding node will rebroadcast the NP message for a few times before initiating the query replying process if there is still no acknowledgement. The current forwarding node unicasts the TC message to the first acknowledging neighbor in each road segment, which is then promoted to become the next forwarding node. The example of this process is shown in Figure 4. First, current forwarding node S broadcasts NP message [Figure 4(a)]. Then, node N_1, N_2, and N_3 compute their waiting time. Second, N_3, which has the smallest waiting time, unicasts acknowledgment to S while N_1 and N_2 will stop waiting after they hear the acknowledgment [Figure 4(b)]. Finally, S unicasts the TC message to N_3 [Figure 4(c)]. To propagate a message over intersection, the current forwarding node will forward the TC message to the first acknowledging neighbor in each road segment that moves forward from the current road segment. The criteria of responding to the NP message are listed in [18].



(a) Node S broadcasts neighbour probing message.



(b) Node N_3 unicasts acknowledgment to S



(c) Node S unicasts traffic collector message to N_3.

Figure 4: Basic mechanism of RTC protocol.

Query replying is initiated when the current node receives no acknowledgement for the NP message after a few retries. In this phrase, the most-forward routing similar to the query dissemination phrase is used. However, the message will be forwarded along the route that the query message has traveled.

RTC uses most-forward-routing strategy, which is based on the distance from the current forwarding node. After neighboring nodes receive an NP message, they will wait for T_w before returning acknowledgment. The waiting time is computed by using the same simple distance based function with EDB [Equation (2)].

2.4.2 Implementation decisions

To compare RTC to other selected protocols in terms of the performance of query spreading over selected road segments, it is unnecessary to reply the information back to the source. Thus, RTC is implemented without using query replying phrase. The traveled road segments in the TC message will be saved when the replying phrase is triggered and then the message will be dropped.

2.5 *Common modification*

In EDB, we found that message collisions occur if neighbor locations are very close because of very small difference in their waiting time. This issue also happens in Slotted 1-persistence when the neighbors locate in the same slot. So, an additional random value between 0 and T_{max} has been added to the waiting time Equations (1) and (2). This random value also benefits to RTC in that unnecessary acknowledgment is eliminated.

To deal with multi-query sessions, all the protocols except RTC are enhanced with a source id, message id, and destination location to identify a query session. Those three protocols are also applied with ZoQ as an area of interest to steer the message propagation over the specific pre-defined road segments.

3 Methodology

3.1 *Simulation model*

The simulation model is developed in OMNet++ version 4.5 with INET framework version 2.2 for simulating a network mechanism, and Simulation of Urban Mobility (SUMO) version 0.15.0 for simulating the road topology and node mobility. The simulation was run in a machine with 2.4 GHz 8 core CPU and 64 GB memory.

The simulation is divided into three main scenarios: (i) Large-net scenario, (ii) Background traffic scenario, and (iii) RSU-failure scenario.

Large-net scenario is used to investigate the scalability performance of the selected protocols under a large scale network with node mobility. This scenario is simulated under 8×8 km^2 of a grid network.

Background traffic scenario introduces background traffic to the network. The purpose of this scenario is to investigate performance of the selected protocols in a more realistic setting with interfering traffic from other applications sharing the network. However, we found that the generation of background traffic together with node mobility in such a large-scale network results in prohibitively large amount of simulation time. Therefore, unlike the large-net scenario, this scenario is simulated under a 4×4 km^2 grid network with fixed mobility.

RSU-failure scenario extends the background traffic scenario by introducing a chance of RSU failure in EDB to investigate limitations of protocols with and without the dependency on fixed infrastructure.

For each query session, the source node and the destination location will be placed at the beginning of the randomly selected road segments. Each source node initiates only one query session. The simulation terminates when there is no message left in the simulation.

For the large-net scenario, the mobility parameters are set based on traffic information in Bangkok, Thailand, which is studied in [19]. The simulation parameters are summarized in Table 1. The protocol parameters are chosen based on the setting in their work and summarized in Table 2.

Table 1: Simulation parameters

Network Parameters	
Transmission Power	2 mW
Path-loss Model	Two-ray ground model with path-loss exponent 2.0
Network Topology	8×8 km^2 grid and 4×4 km^2 grid with 4 lanes (2 in each direction)
Transmission Rate	2 Mbps
Communication Range	~150 m
Simulation Time	Until no message left in the simulation
Mobility Parameters	
Maximum Speed	17.7 km/hr
Acceleration	0.674 m/s^2
Deceleration	–0.687 m/s^2
Car following model	SUMOKrauβ

Table 2: Protocol parameters

Slotted 1-persistence	
Number of slots (*Ns*)	5
Maximum waiting time (T_{max})	10 ms
The waiting time for duplicated message (*WAIT_TIME*)	10 ms
EDB	
Number of repeat broadcast	6
Maximum waiting time (T_{max})	10 ms
DRIVE	
No special parameter	
RTC	
Neighbours' response timeout (Tnp)	10 ms
Number of retrying to broadcast NP message	6
Number of shortest paths in ZoQ	5

In the large-net scenario, the following performance measures are considered:

- **Percentage of target road segment coverage**: The ratio of the number of road segments traversed by the query message and the total number of target road segments.
- **Delay**: The time taken from the query message has been sent by a source until the time of the last query message received.
- **Total packets transmitted**: The total number of all kind of message used in the simulation.

For the other two scenarios, only the percentage of target road segment coverage is considered.

3.2 *Experimental setup*

To investigate the scalability of the studied protocols, the simulation is simulated following factors: the number of query sessions and the node density.

3.2.1 Large-net scenario

- **Node mobility**: To simulate mobility and movement path in SUMO, predefined routes of the node movement trajectory are required. Each node will be removed from the simulation when it reaches to the end of the route. If the current forwarding node reaches to the end of the route, the current forwarding node will be removed and the message will be lost. To prevent such situation, each node is configured to run in a circular route. Every node except those on outermost road segments will turn left at every intersection they encounter as shown in the movement path of N_1 in Figure 5. Nodes on the outer road segments will only run on the outer road segments and turn right at the corners of simulation map as shown in the movement path of N_2 in Figure 5. At the beginning, the nodes will be released at the beginning of each road segment. Then, the nodes will run in circles. To collect road traffic information of a road segment, the road segment must contain a sufficient number of nodes. In default behavior of SUMO, when nodes encounter at the junction, nodes on a low priority road segment have to wait until those on a high priority road segment have passed the junction. If all road segments have the same priority, nodes coming from the right side will go first. Thus, the nodes will not move if there are a lot of nodes coming from the right side and the most of nodes will be grouped around the intersection. To make the cars flow smoothly without excessive cluttering at intersections, we modify the default behavior of SUMO such that each node will turn left or turn right without stopping at the intersection. The default car-following model in SUMO is SUMOKrauβ, which lets vehicles move farthest while maintaining highest safety.
- **Number of query sessions**: The average route distance for randomly selected source and destination locations in a query session is 18.1 km in an 8×8 km^2 network. The number of query sessions between 1 and 20 are used.
- **Node density**: With a node transmission range of 153.4 m and a 1 km road segment, the node density should be at least $\frac{1{,}000}{153.4} = 6.5$ vehicles/km/lane to maintain the network connectivity. So, the range of node density is set between 40 to 100 nodes/road segments. The source nodes will be placed at the beginning of their route. Then, the rest of nodes (in 1 km) are set to run from the beginning of each road segment until the number of nodes reaches to the maximum number of nodes per km and the transient period of 30 seconds is used before starting the query sessions. Within 30 seconds, source nodes can move around $\frac{1.77 \times 1{,}000}{3{,}600} \times 30 = 147.5$ m,

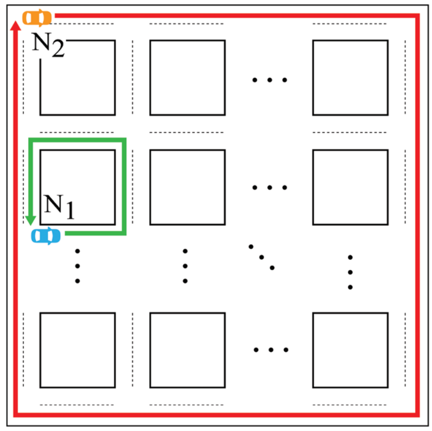


Figure 5: A movement path of nodes in the large-net simulation scenario.

and thus they still belong to their initial road segment of the movement path.

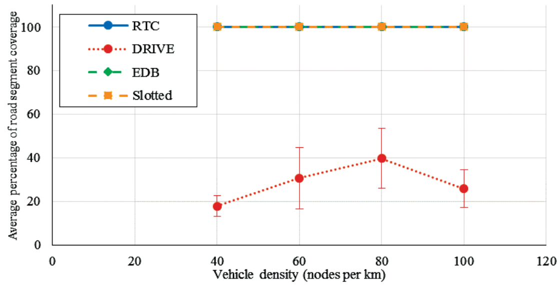
3.2.2 Background traffic scenario

- **Number of query sessions**: The average route distance of all randomly selected source and destination locations under a 4×4 km^2 network is 15.8 km. The number of query sessions is set to 75 sessions.
- **Node density**: The density at 40 vehicles/km and 80 vehicles/km are used in this scenario. To maintain the network connectivity under a fixed node scenario, the nodes are evenly distributed over the road segments.
- **Background traffic**: The maximum background message is set to 30% of channel transmission rate (C). In case that all nodes broadcast background messages with probability 1, the total size of background messages that each node has to broadcast (T_{bg_max}) is $T_{bg\_max} = \frac{C}{N}$ where N is the average number of nodes within a transmission range. Because the nodes are static, the average number of nodes within transmission range can be calculated by using the network density. In this scenario, the size of background message is 250 bytes. So, the time interval (t) that each node has to broadcast the background traffic is $t = \frac{MessageSize}{T_{bg\_max}}$. For example, at density 40 vehicles/km, the number of nodes within transmission range (N) is 12. Therefore, the time interval (t) that each node has to broadcasts the background message is 0.04s. To study the performance of the selected protocols under background message scenario, the probability to broadcast the background message is varied from 0 to 1.

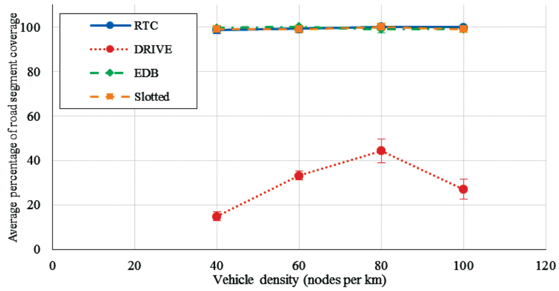
3.2.3 Background traffic with RSU fail scenario

All setting of this scenario is the same with the background traffic scenario except that at most 10% of RSUs is assumed nonfunctional.

For all the scenarios, the simulation of each factor level combination described above is repeated for five runs and the average of performance measures are computed with 95% confidence interval shown whenever possible.



(a) Single query session.



(b) 20 query sessions.

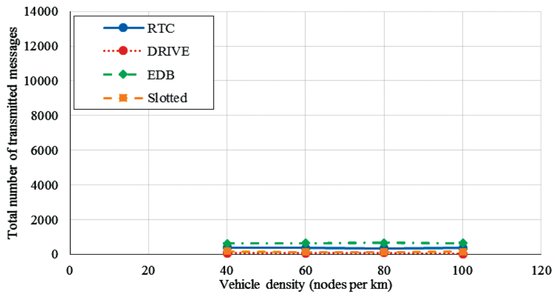
Figure 6: Average percentage of target road segment coverage in large-net scenario.

4 Simulation Results

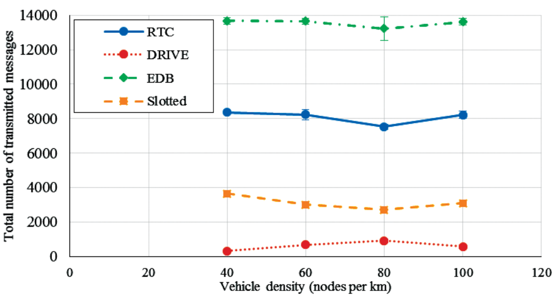
4.1 *Large-net scenario*

4.1.1 Effects of node densities

From Figure 6, the query message in Slotted 1-persistence, EDB, and RTC can be disseminated all over target road segments in all node densities. For DRIVE, target road segments are better covered when the density increases due to the sweet spot mechanism. The last rebroadcast node in a road segment at low density is farther from an intersection than the last rebroadcast node at high density. So, only one sweet spot in the forwarding direction of the last rebroadcast node at low density covers all connected road segments. With the rule that allows only one rebroadcast node in each sweet spot, a message will be forwarded over only one road segment. At high density, the sweet spots in three directions (front, left, and right) of the last node in current road segment cover all connected road segments by using one sweet spot per road segment. Thus, a message can be disseminated to all road segments connected to the intersection. However, at 100 vehicles/km, the

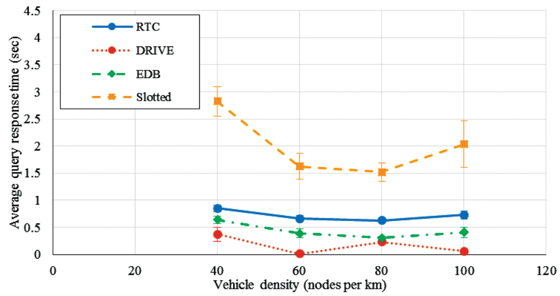


(a) Single query session.

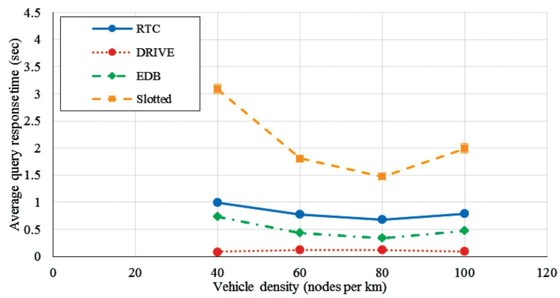


(b) 20 query sessions.

Figure 7: Total number of transmitted messages in large-net scenario.



(a) Single query session.



(b) 20 query sessions.

Figure 8: Average last target road segment coverage time in large-net scenario.

percentage of target road segment coverage is drop to 30%. Due to mobility, the last node will move to new road segment and the second to last node, which is farther from the intersection than the last node, will be selected as the next forwarding node. Thus, the probability that only one sweet spot covers all of connected road segments is increased. DRIVE also suffers from the case that there are two nodes have very close waiting time and these two nodes rebroadcast a message. Next hop neighbors start waiting for the first received the message and then cancel the waiting by received the second message. This problem is resolved in highway environment in DRIVE proposed work.

However, it clearly indicates in DRIVE that the mechanism to resolve the mentioned problem is only used in a highway environment, not in a city environment.

Figure 7 shows the total number of transmitted messages. The total number of transmitted messages is not significantly dropped when the node density increases due to the broadcast storm suppression technique of each protocol. At higher node density, the dissemination can make higher progress due to the farther neighbor locating closer to the border of the transmission range.

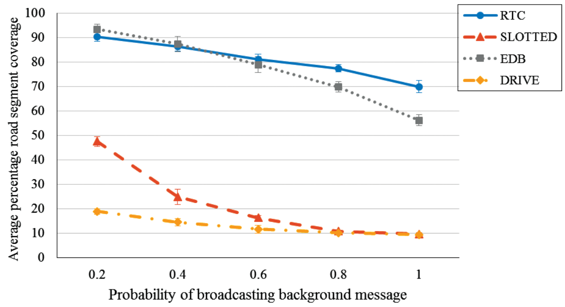
Figure 8 shows the average last target road segment coverage time. The time decreases as the node density increases because the waiting time of all protocols are inversely proportional to the distance between neighbors and the current forwarding node and the distance of farther neighbors is proportional to the node density. However, at 100 vehicles/km, there is high probability that the farthest node moves to another road segment and the second to farthest node will be selected as the next forwarding node. Thus, the waiting time will be increased, which leads to a higher average last target road segment coverage time. Notice that, as mentioned before, RTC uses 3 messages per rebroadcast. So, it should use more time than other protocols. However, Slotted 1-persistence takes the highest last target road segment coverage time due to the waiting time function of slot-based mechanism and the mechanism to wait for duplicate messages.

4.1.2 Effects of query sessions

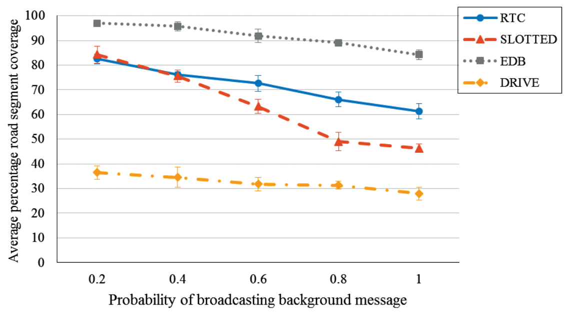
Figures 6(a) and 6(b) show the average percentage of target road segment coverage of 1 and 20 query sessions respectively. As can be observed, increasing number of query session to 20 does not affect the average percentage of target road segment coverage. In Figure 7(a), all protocols use less than 1,000 messages. From Figure 7(b), the total number of transmitted messages is proportional to the number of query sessions. RTC uses two small probe messages and one data message for each rebroadcast, while EDB uses one acknowledgment message and one data message. Slotted 1-persistence and DRIVE use only one data message for each rebroadcast. Therefore, the total number of transmitted messages in RTC is larger than other protocols. However, EDB uses the highest total number of transmitted messages because the neighbors have very close waiting time. When two or more neighbors have very close waiting time, RTC generates duplicate acknowledgment while EDB generates duplicate acknowledgment and data. Moreover, at an intersection, EDB makes a shorter forwarding progress than other protocols because it needs RSUs to broadcast a message over the intersection.

4.2 *Background traffic scenario*

The performance of the selected protocols in terms of road segment coverage is shown in Figure 9. At density of 40 vehicles/km, the result shows that RTC can cover more than 90% of total road segment and drop to 70% when the number of background messages increases as shown in Figure 9(a). EDB also covers more than 90% at the lowest number of background messages and dramatically drops to lower than 60% when the environment has higher number of background messages. Those two protocols can cover the road segment in the presence of background traffic due to the reliable mechanism used to rebroadcast a message. RTC also has the advantage from the unicast mechanism while Slotted 1-persistence and DRIVE use the broadcast mechanism without rebroadcasting a message when the message is lost. EDB uses RSU to rebroadcast a message without delay at intersections. With the most-forwarding strategy, the number of hops is inversely proportional to the density. Thus, EDB outperforms other protocols in terms of the road segment coverage at high density as shown in Figure 9(b). For Slotted 1-persistence, the performance is better at lower density due to its slotted mechanism. At 80 vehicles/km, more nodes are within the transmission range than at 40 vehicles/km. Also, there is a node at further slot at



(a) Density at 40 vehicles/km.



(b) Density at 80 vehicles/km.

Figure 9: Average percentage of target road segment coverage in background traffic scenario.

80 vehicles/km which means smaller delay time. The effects of node densities are the same trend with the large-net scenario.

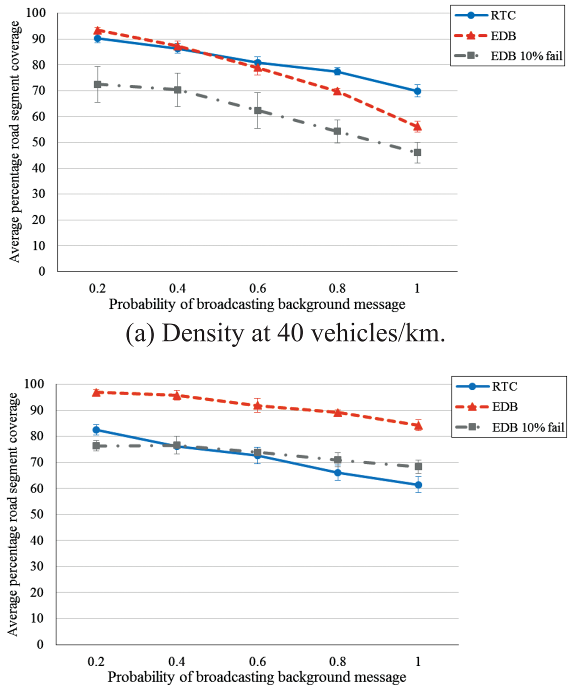
4.3 *RSU-failure scenario*

From the background traffic scenario, EDB outperforms other protocols in terms of the road segment coverage. However, EDB requires the stationary node or RSU at every intersection. In Figure 10, when there is 10% of RSU are nonfunctional, the coverage road segment is dramatically dropped because messages cannot be delivered through intersections with failed RSUs.

RTC, on the other hand, would be considered more fault-tolerant as it does not rely a fixed network component.

4.4 *Message complexity analysis and key results*

Regarding the number of messages used per hop, in the best case, Slotted 1-persistence and DRIVE use only 1 message per hop while EDB and RTC use 2 and 3 messages respectively. In the worst case, Slotted



(a) Density at 40 vehicles/km.

(b) Density at 80 vehicles.

Figure 10: Average percentage of target road segment coverage in RSU-failure scenario.

1-persistence and DRIVE use only 1 message per hop because there is no mechanism to resolve a message loss. With the setting of 6 retransmission attempts in EDB and RTC when a message loss is detected, EDB uses 12 messages per hop and RTC uses 18 messages per hop.

Due to their dissemination mechanism, Slotted 1-persistence, EDB, and RTC work perfectly by covering 100% of road segment under all the node density while the road segment coverage of DRIVE increases when the node density is raised. DRIVE can cover road segment around 20% at 40 vehicles/km and rises up to 40% at 80 vehicles/km then drops to 30% at higher vehicle density. However, EDB requires RSU and its road segment coverage drops around 20% when 10% of RSUs becomes nonfunctional. For the query response time, Slotted 1-persistence takes around 3 seconds at 40 vehicles/km and lower if the node density increases while the other protocols take lower than 1 second under all densities. The total number of transmitted messages of all protocols are significantly different under all densities.

The average percentage of road segment coverage and the query response time of each protocol are not significantly affected by the number of query sessions. With the presence of background traffic, RTC provides most robust performance than all the others. For example, at low background traffic, the road segment coverage of both EDB and RTC is around 90% but that of EDB drops to lower than 60% while that of RTC only drops to 70% when the background traffic load is increased. In the same situation, Slotted 1-persistence covers around 50% of road segments and then drops to 10% while DRIVE covers 20% of road segments and drops to 10%.

5 Conclusions

This paper compares several data dissemination protocols in a vehicular ad hoc network including Slotted 1-persistence, EDB, DRIVE, and RTC for road traffic collecting application. Their behavior in a large scale network and under multiple query sessions and the presence of interfering background traffic are evaluated. EDB is the fastest message propagation with high percentage of road segment coverage but it uses the highest number of total messages transmitted. EDB also requires RSUs, make it more susceptible to equipment failure. When a small fraction of RSUs fails, the performance of EDB drops dramatically. Slotted 1-persistence uses the lowest number of total messages transmitted at the expense of slowest message propagation. In large-net scenario, RTC comes to the middle between EDB and Slotted 1-persistence. Its message propagation time is faster than Slotted 1-persistence and uses the lowest number of total messages transmitted than EDB. DRIVE has inferior performance compared with the other three protocols. Its broadcast storm suppression mechanism is improper to use with the environment that the transmission range is much smaller than a road segment and the environment that requires at least one node in each selected road segment to be a relay node. In the presence of interfering background traffic, RTC outperforms other protocols without requiring any stationary node.

With the message dissemination technique of the selected protocols that use the farthest neighbour as the next forwarding node, those protocols give best performance when the farthest neighbour locates at the border of the transmission range of a current forwarding node. Therefore, the performance of those protocols improve when the node density increases until the distance between the farthest neighbour and the current forwarding node reaches the radius of the communication range. Beyond that, the query response time of Slotted 1-persistence will increase and the road segment coverage of DRIVE will drop.

Acknowledgments

This research is supported by Thailand Research Fund through the Royal Golden Jubilee Ph.D. program under grant no. PHD/0309/2552.

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