Light-Weight Reliable Broadcast Message Delivery for Vehicular Ad-hoc Networks

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Abstract—**Reliability as well as efficiency of transmissions is of a paramount issue for the safety critical services of VANET due to the urgency and/or significance of the messages. To this end, various retransmission mechanisms have been studied for reliable broadcast message delivery in VANETs. Most of the existing approaches, though, rely on periodic beacons for retransmission decisions and intrinsically require high control overheads. Especially, in urban environments where the traffic density tends to be high, minimizing control overheads is important not only for the efficiency but also for the reliability of user message delivery. In this paper, we propose an efficient broadcast message delivery mechanism, which does not rely on the periodic beacon exchanges. Based on the observation that the broadcast message delivery could be particularly difficult at the intersections due to the signal diffraction and attenuation caused by the obstacles such as buildings around the corners of the intersection, a novel mechanism to make efficient and effective retransmissions across an intersection is proposed. Simulation results show that the proposed mechanism can provide similar or better reliability while incurring prominently less overheads than the existing approaches.**

***Keywords*-VANET, broadcast message, reliability, efficiency, beaconless, urban scenario, intersection**

I. INTRODUCTION

Vehicular Ad-Hoc Networks (VANETs) attracts increasing interests due to the plethora of services which may be developed over them. The vehicular communication services range from critical safety applications and traffic management to infotainment applications. Delivery of broadcast messages is of great importance for the successful deployment of the vehicular communication services since many of them rely on the delivery of broadcast messages to the vehicles within a specific area. Especially for the safety critical services reliability as well as efficiency is of a paramount issue due to the urgency and/or significance of the messages.

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For the intermittent disconnection is one of the main challenges in providing reliable message delivery over VANETs, mechanisms to choose robust routes i.e., routes with good connectivity among vehicles, have been studied extensively [1][2][3][4]. On top of selecting a robust route, an efficient retransmission mechanism, which first detects whether there is a vehicle which missed the message and retransmit the message if necessary, is required for the reliable delivery of broadcast messages. [5] and [6] proposed such retransmission mechanisms exploiting periodic beacons. Since these mechanisms rely on the information exchanged by the beacons, loss of beacons due to collisions or transmission errors may be critical. [7] proposed a mechanism for a vehicle to piggyback its neighbors' beacon information so that figuring out the surrounding condition is still possible even when a beacon is lost.

In Geobroadcasting-Slotted Restricted Mobility Based (G-SRMB) [5], a forwarding vehicle of a broadcast message regards the rebroadcast of the message by the next forwarding vehicle as the implicit acknowledgement. If a forwarding vehicle of a broadcast message does not hear the broadcast of the message by the next forwarding vehicle within a timeout period, the message is assumed to be lost and rebroadcasted. In G-SRMB, vehicles exchange periodic beacons with the neighboring vehicles to collect location information of the neighbors. Based on this information, the farthest neighbor of the current forwarding vehicle is designated as the next forwarding vehicle of the broadcast message. Furthermore, the other neighboring vehicles also rebroadcast the message if there is a chance that one or more of their neighbors have not received the message taking into account the neighbors' location information. The rebroadcasting order among the vehicles is determined by the rebroadcasting timer value, which is set reverse proportional to the distance from the forwarding vehicle.

Acknowledged Parameterless Broadcast in Static to highly Mobile (AckPBSM) [6] also utilizes periodic beacons. In AckPBSM, not only the location information but also the identifications of broadcast messages received are exchanged among the neighbors. Based on this information, vehicles in the Connected Dominating Sets (CDS) [8] is determined in a distributed way, and they basically take charge of the forwarding of the broadcast message. The non-CDS vehicles may also rebroadcast the message if they have a neighbor that has not received the message. Upon receiving a broadcast message, the non-CDS vehicles estimate the number of

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neighbors that may not have received the message taking into account the neighbor's location, and set its rebroadcast timer with the value that is reverse proportional to that number. Using the information in the beacon (i.e., the identifications of broadcast messages received), each vehicle updates and maintains the list of neighbors that have not received the broadcast message, and repeats the rebroadcast until all of its neighbors receive the broadcast message.

G-SRMB and AckPBSM achieve efficient and fast delivery of broadcast message by making the farthest vehicle from the current forwarding vehicle or the vehicles in CDS take charge of the forwarding of the broadcast messages, while enhancing the reliability by letting the other vehicles, i.e., the non-forwarding vehicles rebroadcast if they have neighbors that have not received the message. AckPBSM ensures that every vehicle receives the message by explicitly exchanging received message identifications among the neighbors and by repeating the rebroadcast until there is no neighbor that has not received the message. On the other hand, G-SRMB only relies on the neighbors' location information instead of the explicit received message identifications to decide whether such neighbors exist.

Since both G-SRMB and AckPBSM are based on the periodic beacons, the control overhead could be significant, and tradeoff exists between the performance and the amount of beacon overhead. Especially AckPBSM may require more extensive wireless resource consumption since it requires the explicit exchanges of received message identifications among the neighbors. On the other hand, even though G-SRMB requires less beacon overhead than AckPBSM, it may not be able to correctly figure out whether there is a neighbor that has not heard the broadcast message.

In this paper, we propose a light overhead reliable broadcast message delivery mechanism, which does not rely on periodic beacons. The proposed scheme is based on the Contention-Based Forwarding (CBF) [9]. In CBF, the farthest vehicle from the current forwarding vehicle becomes the next forwarding vehicle. The forwarding vehicles are implicitly and distributively determined at the receiving side. The vehicles receiving a broadcast message set their forwarding timer value reverse proportional to the distance from the current forwarding vehicle to themselves. A vehicle cancels its forwarding timer i.e., the transmission of the received message if rebroadcast of the message by another vehicle is heard before its forwarding timer expires. Since CBF is a receiver oriented forwarding mechanism, no beacon is necessary.

Similar to G-SRMB, the proposed mechanism detects the failure of broadcast delivery based on the implicit acknowledgement and the forwarding vehicle rebroadcasts upon the detection of delivery failure. The novelty of the proposed mechanism is how the broadcast message is forwarded across the intersections, which frequently appears in the urban street layout. It is based on the observation that it is difficult for a broadcast message to be propagated through the streets that are crossing the road on which two consecutive forwarding vehicles are located due to the obstacles such as buildings around the corners of intersections. The proposed mechanism ensures the successful delivery of the broadcast message over the crossing streets at the intersections, as long as connectivity exists, in an efficient and fast way.

In section II, the proposed mechanism is explained in detail with an illustration on the inefficiency and/or the ineffectiveness of the existing mechanisms with respect to the delivery of the broadcast messages over the intersections. In section III, the performance of proposed mechanism is compared with the performance of existing mechanisms through a simulation. Finally, concluding remarks are given in section IV.

II. LIGHT-WEIGHT RELIABLE BROADCAST MESSAGE DELIVERY

The proposed light-weight reliable broadcast message delivery (LW-RBMD) mechanism is first explained in section A. In section B, the specific merits of LW-RBMD are illustrated in detail through the comparisons to the existing reliable broadcast message delivery mechanisms.

A. Broadcast Message Delivery by LW-RBMD

LW-RBMD relies on the availability of real time information on the location and the velocity of a vehicle as well as the surrounding street layout, which can be readily obtained from GPS and digital map. Each vehicle maintains the above information of its own, but do not need to exchange it among the neighbors. It is assumed that the objective of broadcast message is to inform the vehicles located on the streets which are within n intersections from the spot where the event (e.g., severe traffic jam, accident, harsh road condition, etc.) occurred in order to enable the vehicles to take appropriate reactions (e.g., detour or slow down, etc.).

LW-RBMD deploys CBF, which does not rely on periodic beacons, as its basic broadcast message forwarding mechanism, and defines the extensions to CBF for reliability enhancement: 1) the message forwarding failure detection scheme, 2) the rebroadcast scheme to recover the failure. Especially the rebroadcast scheme of LW-RBMD focuses on reliable and efficient delivery across the intersections, where the difficulty in message delivery is usually caused by the obstacles such as buildings around the corners of the intersections.

For the message forwarding failure detection, LW-RBMD deploys the similar approach that G-SRMB takes: the broadcast of $(n+1)^{st}$ forwarding vehicle is considered as the implicit acknowledgement by the n^{th} forwarding vehicle. Upon broadcasting a message, the forwarding vehicle starts a rebroadcast timer, whose value is set as follows:

$$RT_{timeout} = MaxWT + 2 \times MaxPT \qquad (1)$$

, where MaxWT is the maximum forwarding delay defined in CBF, and MaxPT is the propagation delay for the maximum transmission range of a vehicle. If the forwarding vehicle hears the broadcast of forwarded message by another vehicle before its rebroadcast timer expires, it is assumed that the message is successfully forwarded to its neighbors and the responsibility of broadcast message delivery is now tossed over to the next forwarding vehicle, and the rebroadcast timer is canceled. Otherwise, the forwarding vehicle repeats the above rebroadcasting process up to the maximum number of times until the implicit acknowledgement is heard.

The proposed LW-RBMD deploys a novel approach for the complementary rebroadcasts. Let us use the terminology 'complementary rebroadcast' as the rebroadcast by the non-forwarding vehicles. Note G-SRMB is a sender oriented approach and the $(n+1)^{st}$ forwarding vehicle is explicitly designated by the n^{th} forwarding vehicle based on the exchanged location information, whereas, it is determined in an implicit receiver oriented way in LW-RBMD. In G-SRMB, a non-forwarding vehicle that finds a neighboring vehicle whose location is not within the transmission range of the forwarding vehicle makes the complementary rebroadcast of the message. In LW-RBMD, on the other hand, only the vehicles within the intersection zone(hereinafter, they are called 'intersection vehicles')perform the complementary rebroadcasts. Figure 1(a) shows that the radio signal transmitted from vehicle A may not reach the shaded area even though the area is within its transmission range due to the signal diffraction over an obstacle such as buildings [11]. We define that the 'intersection zone' is an area at the center of intersections as shown in Figure 1(b), within which the signal attenuation caused by diffraction of radio waves over the obstacles around the corners of the intersection is minimized.

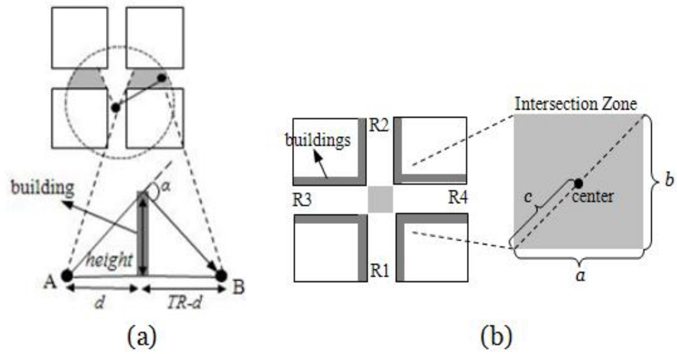


Figure 1 Intersection zone

Considering the relatively limited scale of the realistic streets compared to the transmission range of a vehicle, it is rare that a neighbor is judged to be not within the transmission range of the two consecutive forwarding vehicles if the location information is the only item taken into account for that judgment as it is done in G-SRMB. In order for a vehicle to realistically determine whether some of its neighbors cannot hear the broadcast of the forwarding vehicle, more complicated information and computations than just the location of a neighboring vehicle are required. For instance, the detailed local view of street layout including the obstacles such as the buildings and the relationship of neighboring vehicles in terms of their location versus the direction of transmission propagation, etc. need to be taken into account. This could be a whole new approach incurring a large computational and communication overhead, and is out of the scope of this paper.

In LW-RMBD, we take the approach that avoids the periodic beacons to minimize the waste of wireless resources while making the rebroadcast as effective and efficient as possible by exploiting the complementary rebroadcast at the intersections. When there is no intersection between the two consecutive forwarding vehicles, LW-RMBD entrust the reliability of message delivery to the failure detection and rebroadcast performed by the forwarding vehicles. On the other hand, for an efficient and effective reliable forwarding across the intersections, LW-RMBD makes the intersection vehicles participate in the complementary rebroadcast. Furthermore, the vehicle that is nearer to the center of the intersection area obtains higher priority to perform the complimentary rebroadcast.

To these objectives, an additional rebroadcast timer, intersection rebroadcast timer (IRT) is defined. The vehicles in the following situations set their IRT: 1) a forwarding vehicle that is moving toward the intersection zone with the intersection zone being within its transmission range, 2) a vehicle that receives a new broadcast message while it is moving toward the intersection zone with the intersection zone being within its transmission range, and 3) an intersection vehicle receiving a new broadcast message. Figure 2 shows these three cases. Note, together with IRT, the ordinary rebroadcast timer (in case 1)), and the forwarding timer (in cases 2) and 3)) are also set and utilized independently.

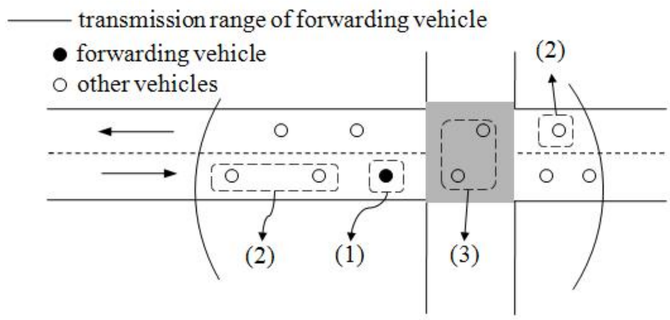


Figure 2 Three cases to set IRT

For 1) and 2), IRT is first set to the maximum value IRT_{max}, which is supposed to be large enough so that IRT may not expire before the vehicle reaches the intersection zone. Upon arrival at the intersection zone, IRT is reset according to the formula for the intersection vehicle's IRT. Formula (2) defines the IRT value for the intersection vehicles. According to formula (2), the vehicle that is nearer to the center of the intersection area has the higher priority of rebroadcasting. It is based on the assumption that the nearer to the center of intersection is the lower the chance of signal attenuation by the obstacles around the corners of the intersection.

$$IRT_{timeout}^{intersection\_vehicle} = MaxWT \times \frac{D_{vehicle\_to\_center}}{c} \quad (2)$$

, where MaxWT is the maximum forwarding timer value as defined in CBF, $D_{vehicle\_to\_center}$ is the distance from the vehicle to the center of intersection, and c is half the length of diagonal of the intersection zone, which is $\sqrt{a^2+b^2}/2$ (see Figure 1(b)).Note, as a result of how the IRT value is set, if more than one intersection vehicles exist at the forwarding instance, the nearest one to the center of the intersection zone takes charge of the rebroadcast. Otherwise, the vehicle that reaches the intersection zone first becomes the one taking charge of the rebroadcast.

While the ordinary rebroadcast timer or the forwarding timer is canceled when a single implicit acknowledgement is heard, IRT is not canceled until the implicit acknowledgement is heard from every branch of the intersection in order to ensure that the message is propagated through every branch of the intersection. When IRT expires, the corresponding vehicle rebroadcasts the message, whereas the other vehicles which hear this rebroadcast cancel their IRT. Once a vehicle rebroadcasts due to the IRT expiration, it keeps rebroadcasting in every rebroadcasting interval until the successful forwarding onto every branch is ensured, up to the maximum number of times. Once expired, the rebroadcasting interval of IRT also follows formula (1), which defines the rebroadcasting interval for an ordinary rebroadcast timer.

Figure 3 is the pseudo code for the forwarding and rebroadcasting mechanism of LW-RBMD.

Reception of a broadcast message
If (new message)
  Save the message
  Set forwarding timer
  If (intersection vehicle)
    Set IRT $= MaxWT \times \frac{D_{vehicle\_to\_center}}{c}$
  Else if (intersection within TR && approaching intersection)
    Set IRT $= IRT_{max}$
Else
  If (forwarding timer is running)
    Cancel forwarding timer
  If (RT is running)
    Cancel RT
  If (IRT is running)
    If (implicit ACK from all branches || msg from intersection vehicle)
      Cancel IRT
    Else
      Keep waiting implicit ACK

Timer expiration
If (forwarding timer)
  Broadcast the message
  If (intersection vehicle)
    Set IRT = RT $= RT_{timeout}$
  Else if (intersection within TR && approaching intersection)
    Set IRT $= IRT_{max}$, RT $= RT_{timeout}$
  Else
    Set RT $= RT_{timeout}$
  Wait for implicit ACK
Else if (RT)
  If (num. of rebroadcast by RT less than maximum)
    Broadcast the message
    Num. of rebroadcast by RT++
    Set RT $= RT_{timeout}$
    Wait for implicit ACK
Else if (IRT)
  If (num. of rebroadcast by IRT less than maximum)
    Broadcast the message
    Num. of rebroadcast by IRT++
    Set IRT $= RT_{timeout}$
    Wait for implicit ACK

Arrival at intersection zone
If (IRT is running)
  Reset IRT $= MaxWT \times \frac{D_{vehicle\_to\_center}}{c}$

Figure 3 Pseudo code of LW-RBMD

B. Efficiency and Effectiveness of LW-RBMD

In this section, we compare LW-RBMD and a couple of existing approaches, G-SRMB and AckPBSM, in terms of how the broadcast message delivery is done over an intersection with some example scenarios in order to specifically bring the advantages of LW-RBMD to light. Two different scenarios are considered: one with no vehicle in the intersection zone, and another with a vehicle moving inside the intersection zone. Figure 4(a) illustrates the first scenario. Let us assume that A is the forwarding vehicle, and even though A, B, C, D and E are all within the transmission range of each other in terms of the distance, the radio signal from A, D and E may not reach B and C and vice versa due to the signal attenuation caused by the radio wave diffraction at the buildings around the corners.

In G-SRMB, the broadcast message cannot be delivered to B and C in this case since not only the broadcast from A is not heard at B or C, but also neither D nor E makes rebroadcast since they do not recognize B or C as their neighbors. Differing from G-SRMB, AckPBSM may have chance to deliver the broadcast message to B and C. When D moves into the intersection zone, if B and C are still in the transmission range of D, D may find out B and C as its new neighbors that has not received the broadcast message, and may rebroadcast the message for them. Similar to AckPBSM, LW-RBMD is also able to deliver the broadcast message to B and C if D enters the intersection zone before B and C moves away from its transmission range. In LW-RBMD, the first vehicle that enters the intersection zone, which is D in this example, makes the rebroadcast since there is a branching street from which no implicit acknowledgement is heard.

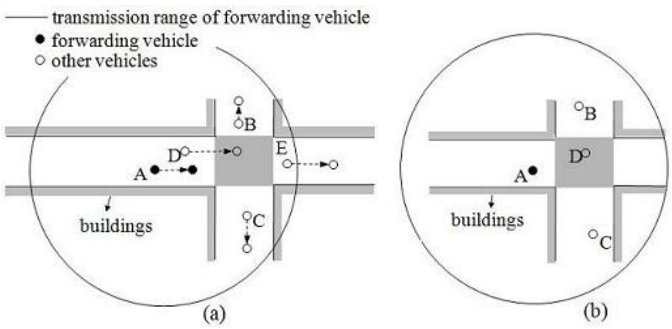


Figure 4 Broadcast message delivery across an intersection

Figure 4(b) illustrates the case where a vehicle (vehicle D in the figure) is located within the intersection zone. Let us assume that A is the forwarding vehicle, and even though A, B, C and D are all within the transmission range of one another in terms of the distance, the radio signal from A may not reach B and C and vice versa due to the signal attenuation caused by the radio wave diffraction at the buildings around the corners. In G-SRMB, even though D traces B and C as its neighbors in this scenario, D may not realize that the broadcast message from A cannot be delivered to B and C and gives up the rebroadcast since they are located within the transmission range of A in terms of the distance. Both AckPBSM and LW-RBMD can successfully deliver the broadcast message to B and C owing to the rebroadcast of D. In AckPBSM, D rebroadcasts the message forwarded by A when B and C are found as its neighbors that has not received the message, whereas, in LW-RBMD, D rebroadcasts the message upon its IRT expiration. Note, however, the maximum latency to rebroadcast is smaller in LW-RBMD. In AckPBSM D has to first find out that B and C are its neighbors before it makes the rebroadcast for B and C, and hence it may take the beacon interval in the worst case until rebroadcasting takes place. On the other hand, in LW-RBMD, the intersection vehicle D rebroadcast the message in the maximum forwarding delay of

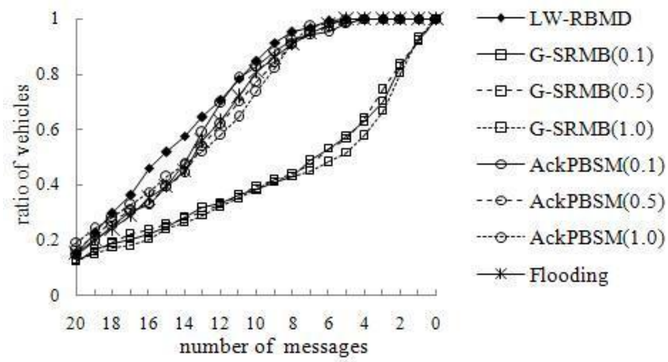
CBF at most, which is generally smaller than the beacon interval. Recall the IRT of the intersection vehicle is set to a value that is smaller than or equal to the maximum forwarding delay of CBF (see formula (2))

III. PERFORMANCE EVALUATION AND ANALYSIS

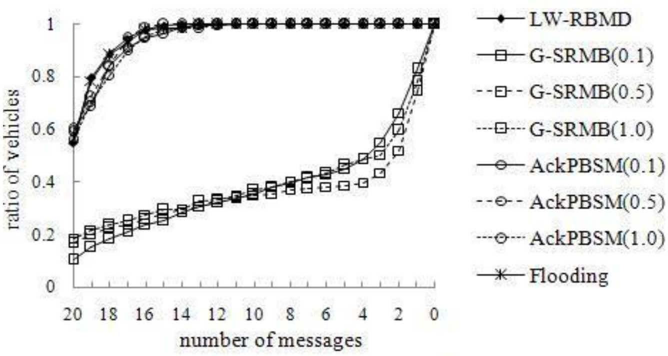
Using OPNet 14.5 simulation, the performance of LW-RBMD is compared with the two existing beacon based reliable broadcast message delivery mechanisms, G-SRMB and AckPBSM, as well as flooding. A section of an urban area with a square grid of 2.4 km per side with 3 intersections of 600m apart on each street is considered. Each street has two lanes in opposite directions with 7.5 m of width per lane. Each intersection has traffic light which gives 6 seconds of stop and running signals in turn. 80% of the vehicles stopped at the traffic light go straight, and the rest of the vehicles make left or right turns with the same ratio respectively. Following the knife-edge model [11], buildings of 10 ~ 20 m tall are located along the street so that radio wave diffraction may occur at the intersections. Two different traffic density scenarios of 288 vehicles (48 vehicles/km^2) and 576 vehicles (96 vehicles/km^2) in the network are considered. The vehicles move with a speed of 14 ~ 18 m/s, and the transmission range of a vehicle is assumed to be 300 m. For G-SRMB and AckPBSM, three different beacon intervals, 0.1 sec, 0.5 sec, and 1 sec, are considered, while for LW-RBMD, the MaxWT of 0.1 sec is assumed. The event requiring the broadcast is assumed to occur in the middle of the network, and the broadcast message is supposed to be delivered to entire vehicles in the network.

In order to evaluate the reliability of broadcast message delivery, the number of messages received at each vehicle is counted. Figure 5 shows the ratio of vehicles that received total *x* or more messages among the 20 broadcasted messages. Figure 5(a) and 5(b) correspond to the vehicle density of 48 vehicles/km^2 and 96 vehicles/km^2 respectively. For all of the compared mechanisms, the reliability is better when the traffic density is higher. For the two beacon-based mechanisms, smaller beacon interval results in slightly better reliability. Regardless of the beacon intervals, G-SRMB shows the worst delivery capability, and the performance of LW-RBMD and AckPBSM approaches to that of flooding. In G-SRMB, the forwarding vehicles are selected only from among the vehicles that are moving toward the message forwarding direction. In urban scenario, this may result in loosing connectivity even when there are vehicles in the other direction. In urban streets, traffic lights frequently appear and as a result vehicles are coalesced in front of the traffic light in one direction while there is an even distribution of vehicles in the other direction. Furthermore, as we have already pointed out in section II.B, G-SRMB has weakness in propagating the broadcast message across the intersections.

In order to measure the efficiency of the rebroadcasting strategy, the number of broadcasting per received message is measured. Figure 6 shows the number of broadcasting, which includes the forwarding as well as rebroadcasting, per received message. Both LW-RBMD and G-SRMB select the farthest vehicle from the current forwarding vehicle as the next forwarding vehicle, and hence, for varying traffic density, the number of forwarding and the number of rebroadcasting done by the forwarding vehicles is approximately the same. The number of complementary rebroadcasting also does not depend on the traffic density of the network in the two mechanisms. In G-SRMB the complementary rebroadcasting is done by the vehicles that find neighboring vehicles located not within the forwarding vehicle's transmission range, which occurs scarcely due to the reasons explained in section II. In LW-RBMD, the complementary rebroadcasting is done by the intersection vehicles, and thus the maximum number of vehicles that make complementary rebroadcasting corresponds to the number of intersection at the maximum. As a result, the number complementary rebroadcasting does not increase as the traffic density becomes greater. Therefore, in LW-RBMD and G-SRMB, the number of broadcasting per received message is smaller for larger traffic density for the number of vehicles receiving the message upon each broadcasting is larger in the denser network. AckPBSM requires the largest number of broadcasting for each received message, i.e., least efficient, among the compared mechanisms. Furthermore, the number of rebroadcasting per received message is slightly grows for higher density. It is due to the particular characteristics of node distribution in the vehicular networks. The CDS selection is quite inefficient [12], and thus, the number of forwarding vehicles is a lot larger than LW-RBMD and G-SRMB.



(a) 48 vehicles/km^2



(b) 96 vehicles/km^2

Figure 5 Ratio of vehicles receiving *x* or more messages

From the results in Figure 5 and 6, it is shown that LW-RBMD is not only competitively reliable but also far more efficient in terms of the number of broadcasting per received message.

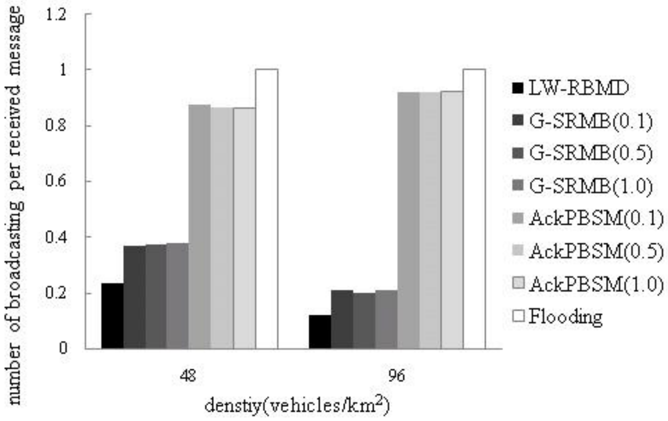


Figure 6 Number of broadcasting per received message

In order to compare the wireless resource consumption, the amount of total traffic generated during the entire simulation period is measured, and is shown in Table I. The measured traffic comprises the beacons and the broadcast messages. Since LW-RBMD does not rely on beacons, it has no beacon traffic while the major source of the traffic is the periodic beacons in G-SRMB and AckPBSM. Even though flooding also does not generate beacons, the amount of broadcasted message is a lot larger than LW-RBMD as expected.

Table 1 Amount of overhead traffic (Mbytes)

density (vehicles/km^2)	48			96		
approach \ beacon interval	0.1	0.5	1.0	0.1	0.5	1.0
LW-RBMD	6.6			9.2		
G-SRMB	3157	637	322	6307	1266	637
AckPBSM	3520	720	369	7060	1459	758
Flooding	7.6			21.5		

IV. CONCLUSIONS

We proposed a beaconless light weight reliable broadcast message delivery mechanism for VANETs. Instead of relying on the neighbor information for the message retransmission decisions, LW-RBMD exploits the real time vehicle location and the velocity, and the street layout information which is readily obtained from the GPS and the digital map installed within a vehicle. LW-RBMD deploys CBF as its basic forwarding mechanism, and utilizes the broadcast of $(n+1)^{st}$ forwarding vehicle as the implicit acknowledgement at the n^{th} forwarding vehicle. While the reliability of delivery between the two consecutive forwarding vehicles located on a straight street with no intervening intersection between them is relied on the failure detection and retransmissions between themselves, the retransmissions by the intersection vehicles are leveraged for the reliable message delivery over and across the intersections. Through a course of simulation, the performance of LW-RBMD is compared with existing approaches: G-SRMB, AckPBSM and flooding in terms of reliability and the overheads. It is shown that LW-RBMD can provide significantly better reliability than G-SRMB, while achieving similar reliability with prominently less overhead than AckPBSM and flooding.

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