Dissemination Protocol for Heterogeneous Cooperative Vehicular Networks

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Abstract—**The difficulties associated with network connectivity, unreliable channels, and city environment characteristics make data dissemination task in vehicular urban networks a real challenge. Recently, some interesting solutions have been proposed to perform data dissemination in this environment. Starting from the analysis of these solutions, we present a new dissemination protocol named DHVN (Dissemination protocol for Heterogeneous Cooperative Vehicular Networks) that considers: (i) roads topology, (ii) network connectivity and possible partitioning in case of low traffic density, and (iii) heterogeneous communication capabilities of the vehicles. We compare our protocol to other dissemination protocols and analyze its performances using NS-3 simulator [1]. Performance studies show interesting DHVN compared to existing solutions. Indeed, DHVN is able to provide a low end-to-end delay, a high delivery ratio and a minimum bandwidth usage since only a limited number of vehicles are involved in the broadcast scheme.**

Keywords — V2X; ITS; cooperative dissemination; store and forward; heterogeneous capabilities; road topology.

I. Introduction

In the last few years, ITS (Intelligent Transport Systems) have been considered as one of the most promising research area since their potential role in enhancing safety and efficiency of our travels. A lot of applications (such as traffic management, hazard warning, driver and passenger information, etc.) are considered vital to achieve this role. These cooperative applications require frequent information exchange between infrastructure and vehicles. Therefore, communications technologies used in ITS will play a pivotal role in the efficiency and effectiveness of such applications and is considered a primary concern in all ITS projects.

The manner in which pertinent information is propagated throughout the vehicular environment is also an important aspect of ITS and is critical to the successful operation of cooperative applications. However, dissemination is usually confronted with two major problems: on one hand, in case of dense traffic, bandwidth proves to be insufficient and it is difficult to limit the packet losses, and on the other hand, if the traffic density is low, temporary disconnection in vehicular network will be unavoidable.

Our aim is to propose a new efficient approach for data dissemination in cooperative vehicular networks. This approach permits to: (i) avoid the waste of bandwidth by optimizing the number of vehicles that have to rebroadcast the packets, taking into account roads architecture as well as network density, (ii) use a store and forward module to limit disconnection effects in a partitioned network, and (iii) deliver the information with a high delivery ratio and a low delay.

To achieve these requirements, we developed a dissemination protocol called DHVN (Dissemination protocol for Heterogeneous Cooperative Vehicular Networks). DHVN optimizes the bandwidth usage by using the same principle as distance-based protocols where the farthest node is selected as relay to propagate data. However, DHVN selects one vehicle for each direction in order to accelerate the propagation. It also accommodates with the vehicular environment and roads architecture: DHVN uses a specific algorithm to optimize the packets retransmission within intersections that makes it suitable especially for urban environment. To fulfill the second requirement, DHVN adds a store and forward mechanism used when no vehicle is able to further disseminate the packets. The last DHVN characteristic is its ability to discriminate relays based on their relaying capabilities. Indeed, it is more appropriate to use tall vehicles with high antenna height than regular vehicles since their radio range is bigger [2].

This paper is structured in four Sections: In the next Section, we introduce the most important related works about dissemination problem in vehicular networks. After that we describe the function of our dissemination protocol. In Section 4 a simulation study is performed that evaluates the performance of the designed solution. Section 5 summarizes and concludes the paper.

II. Literature Review

There exists a plethora of proposed broadcasting protocols for wireless ad hoc networks. Several surveys describe many of them. Here, we only refer to some protocols that have been specifically designed for vehicular networks. Such approaches have been focusing on reducing channel congestion by limiting the number of re-broadcasts with an optimal relays selection and/or adjusting nodes, transmission parameters according to network conditions, notably the transmission power, the transmission rate and/or the contention window.

Due to the space limits, we discuss here some protocols that concern only the concept of relay selection. Such protocols

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could be classified into two categories: stateless broadcast and stateful broadcast. In the first class, there is no need to get information about the network topology. Simple flooding, probabilistic-based and location-based protocols belong to this class. In the second category, the protocol requires information about local topology collected using periodic hello messages exchange. As examples, we can cite: cluster-based, CDS-Based and opportunistic dissemination protocols. In the following some protocols of these two classes are presented.

Simple flooding [3] is the first naive implementation. In this protocol each node receiving a packet retransmits it at most once; if the message is already received it will be ignored. Flooding method results in a serious redundancy and implies a high collision and message losses. To reduce message collisions, different schemes were proposed [4][5]. They aim is to eliminate the redundant message forwarding using probabilistic broadcasting. This means that when a message is received the first time, not all receivers rebroadcast it, but it is only disseminated with probability P, else it is dropped. The probability could be random [4], or depends on neighbours counts [5][6],or depends on the number of received copy of the broadcasted message [7].

Later works proposed a more intelligent location based strategy in which one relay is selected to rebroadcast (usually the farthest away from the source). In DDT (Distance Defer Transfer protocol) [8] only the farthest receiver rebroadcast the message. When a node receives a packet the first time, it initiates a timer that is inversely proportional to the physical distance. Farther is the node, shorter is the backoff timer. The receiver sends the message if it's time-to-live is still positive, and the uncovered region is greater than a certain threshold. Therefore, the message is rebroadcasted by the best relay. This method ensures better coverage with minimum transmissions, which permits to save the bandwidth resource. In CBF (Contention Based Forward) [9], a timer is also triggered before rebroadcasting the message. This timer is calculated using two methods: (i) Distance-based CBF where the timer is inversely proportional to the distance between transmitter and receiver. With this method, the selected relay node is the farthest one. The drawback of this method is the attenuation of radio signal, which implies the inconsistency of information, and (ii) Random-based CBF where a random node is selected as relay. The drawback of this technique is that the selected relay is not necessarily the best relay for the dissemination. In UMB [10], the authors aim to use efficiently the channel and solve the problem of hidden terminal. They introduce new request and reply messages exchange (RTB/CTB: Ready to Broadcast/ Clear to Broadcast) between the sender and the farthest node. This mechanism is similar to RTS/CTS and it concerns the sender and the farthest chosen node for rebroadcasting only. In addition, in each intersection they use repeaters to rebroadcast the disseminated message in order to reach all the directions.

All the methods described above suffer from message losses when no relay is available. MHVB (Enhanced Multi-Hop Vehicular Broadcast) [11] bypasses this problem by retransmitting the packet periodically until the node leaves the dissemination area. Retransmission period is modulated by some parameters (e.g. traffic density). MHVB protocol is composed of two phases: (i) Timer backfires: The node stores the information and calculates the waiting time before retransmission based on the distance from the source of the received packet, and (ii) Traffic Congestion Detection: By counting the number of vehicles surrounding a concerned node. If congestion is detected, MHVB changes the retransmitting period to a new value that is inversely proportional to the number of vehicles around. There are some MHVB improvements that use an angle to focus the rebroadcast in the forwarding direction or also dynamically schedule the backfire timer [12]. In [13] also, the receivers node decide wither or not to rebroadcast the message depending on the coverage threshold and angel between senders and receiver.

Since vehicular networks are also highly partitioned networks, continuous connectivity may not be assumed in a protocol design. To allow long-range information dissemination beyond the extension of a single network partition, concepts from delay-tolerant networking can be applied. In particular, store-and-forward (SNF) approaches could be used. In a SNF approach, nodes do not immediately forward messages, but carry the information along with their movement. When opportunities arise, e.g., by meeting other vehicles, the information is transmitted to forward it further. The SNF depends on applications requirement. In DPP (Direction Propagation Protocol) [14] the vehicles are organized in clusters to propagate the message. It uses the SNF mechanism to solve disconnection issues due to network partition.

LTE4V2X [15] is a novel framework for a centralized vehicular network organization based on LTE technology. It uses a centralized clustering mechanism where the eNodeB is responsible for organizing the distributed vehicular network into clusters and maintaining this structure. The authors propose both collection and dissemination protocols based on this framework. When no LTE coverage is available, a multi-hop extension is proposed. This later is based on CGP (Clustered Gathering Protocol [16]) where the road is divided into fixed short length segments and each segment corresponds to a cluster in order to ensure reachability of an adjacent cluster using a single-hop communication.

We noticed that the majority of existing dissemination protocols fails to reach good delivery ratios in case of low-density network or within an urban environment. In fact, using the farthest vehicle as a relay in an intersection leads to a retransmission of the message but not in all the directions. Furthermore, some of these approaches require the knowledge of local network topology to organize the network into clusters. However, building and maintaining such structure needs frequent update messages exchanges and consumes a big part of bandwidth resources especially in high dynamic networks.

Moreover, these approaches are adapted only in some particular situations. Indeed, they have been developed for an environment fulfilling the following three conditions: (i) homogenous topology where all vehicles are uniformly distributed in space, (ii) homogenous connectivity where the information reception probability is equal in space, and (iii) homogenous communication capabilities where all vehicles have equal transmission capabilities. Unfortunately, the vehicular environment does not fulfill any of them. In the following section, we will give more details on the protocol we propose as a solution to the several limitations.

III. Proposed Protocol Description

In this section we introduce DHVN, our dissemination protocol that aims to support an effective and optimized way to propagate infotainment information in both highway and urban environments. DHVN is a distance-based protocol that takes into account roads' structure and vehicles' heterogeneity to provide a higher chance for vehicles with good dissemination properties (buses, trucks, etc.) to be elected as relays. It solves the limitations of the protocols described in Section 2, by implementing a reliable broadcasting protocol that satisfies the following goals: high delivery ratio, low latency, and minimum bandwidth usage since only a limited number of vehicles are involved in the broadcast scheme.

A. Assumption

In our work, we assume that each node is able to deduce its position using a positioning system (e.g. GPS). Moreover, the vehicles are heterogeneous, 20% of them are one meter higher than normal vehicles (e.g. trucks, buses, etc.). A higher vehicle covers a large area and therefore improves the communication range compared to a regular vehicle. We assume that the node amplifies the signal before rebroadcasting the message, so only coherent message are sent. Moreover no routing is required thus neither routing tables nor paths need to be maintained.

B. DHVN Overview

DHVN is an intersection-based protocol that gives a particular attention to the network connectivity, roads' structure and heterogeneity of the vehicles. To avoid message losses, it introduces new special schemes in intersection regions and for low-density vehicular networks. These schemes are described below.

On the same road, DHVN disseminates the packet in the two directions. Each receiver on the same road triggers a timer based on the distance from the sender. It retrieves the sender position information from the packet header and calculates the backoff timer as follows:

Timer T= 1/(*distance* + *Car_height**(*MD*)) (1)

where *distance* is the distance between the sender and the receiver, *Car_height* is the vehicle's height, *MD* is the maximum additional distance when the node is 1 meter higher (in our case, we find *MD* equal to 125m). An illustration is given in Fig. 1.

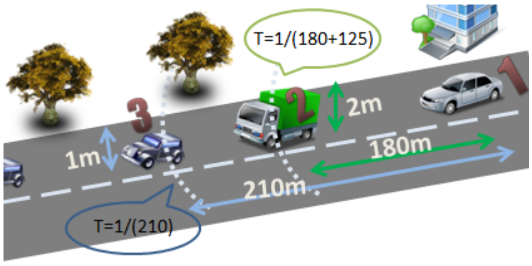


Fig. 1. Node 2, 3 have radio range equal to 375m and 250m respectively, node 2 is higher so the Timer is shorter even it is not the farthest, so it retransmits the message, and node 3 cancels transmission.

As shown in Fig. 2, in each direction the message is propagated in the direction of a predefined outgoing zone. Only nodes with the same road could rebroadcast the received message.

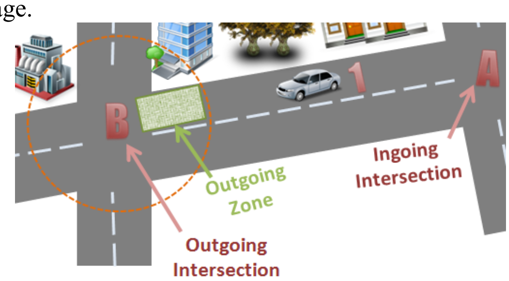


Fig. 2. Vehicle 1 moves from A (Ingoing Intersection) to B (Outgoing Intersection Zone).

Once the relay arrives to the intersection zone and broadcasts the message, all vehicles receiving the message take it into account. One relay is elected for each road and each direction to propagate the message. This should enhance the delivery ratio and latency and avoid packet losses if obstacles are around roads. Fig. 3 illustrates this concept.

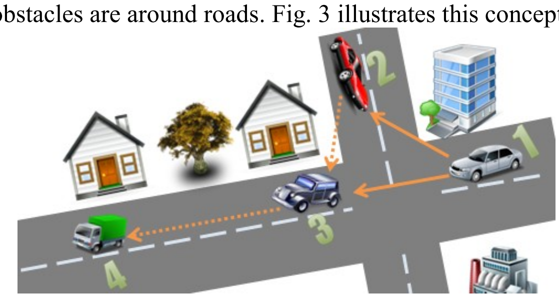


Fig. 3. The two nodes 2 and 3 retransmit the packet received from node 1. Even node 2 is the farthest compared to node 3, DHVN rebroadcasts the message in each direction, so node 4 will also receive it from node 3.

The DHVN algorithm is summarized herein:

Algorithm 1 pseudo-code of DHVN

```
while (Position is in Dissemination Area)
{
function Receive (msg)
{
if (same_road)
 {
    if (first reception)     Trigger timer;
    else
      if (duplicate && sender is before)   Cancel timer;
```

```
      } //end same road
      if (Intersection Zone)
      {
        if (first reception)     Trigger timer;
        else //if the message is already received
         { if (duplicate && sender is not in the same road)
            Ignore the reception and continue to disseminate;
         }
      } //end IO_Zone
    } //end event receive
}//end while
function Timer fired()
  Trigger timer with SNF period;
```

Since vehicular networks are also highly partitioned networks, continuous connectivity is not guaranteed. To allow long-range information dissemination beyond the extension of a single network partition, we used the store-and-forward SNF approach. In our SNF approach, nodes carry the information along with their movement and transmit it periodically. In DHVN, the choice of the SNF period is crucial. Indeed, a small period causes a bandwidth waste and a high period implies a high delay. Therefore, to choose our SNF dissemination period we defined an analytical model described hereafter.

C. The SNF Period

We first defined a mathematical model to represent the probability of connection between two vehicles after exactly one SNF period. Then, based on this model we tried to determine the most appropriate value for the SNF retransmission period. According to many works [17][18] the inter-vehicle distance in vehicular networks could be modeled with an exponential distribution. Thus, the probability to have a multi-hop connection between two x-distant vehicles, *Pc(x)*, is given by [17]:

$$pc(x)=\begin{cases} 1 & if\ 0\le x\le R \\ \displaystyle\sum_{i=0}^{\left[\frac{x}{R}\right]}\frac{\left(-\alpha e^{-\alpha R}(x-iR)\right)^i}{i!}- & \\ \left(e^{-\alpha R}\displaystyle\sum_{i=0}^{\left[\frac{x}{R}\right]}\frac{\left(-\alpha e^{-\alpha R}(x-(i+1)R)\right)^i}{i!}\right) & if\ x\ge R \end{cases} \qquad (1)$$

where r, α, x denote respectively the radio range, traffic density, and inter distance between vehicles, *[x/R]* is the largest integer smaller than or equal to *x/R*.

The probability of connection of two disconnected vehicles after ζ is:

$P(x) = (1-Pc(x))*Pc(x-(SNF*\Delta V))$ (3)

It permits to calculate a minimal necessary period to have an acceptable probability of connection between two disconnected vehicles. This probability depends on the network density, the radio coverage, and the standard deviation of velocity. Using Scilab software [19], we plotted *P(x)* the variation of the probability of connection of two disconnected vehicles as a function of SNF(store and forward) period (see Fig. 4).

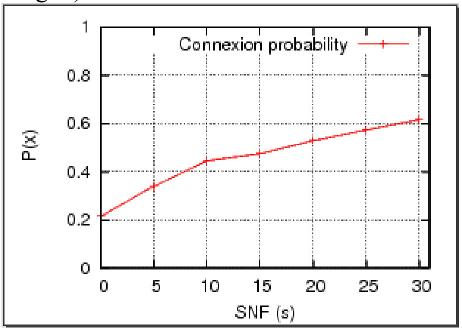


Fig. 4. P(x) when ΔV=40Km/h, SNF = [5-30]s, α=1/radio range.

We can notice that when SNF equals to 0 seconds, the probability of multi-hop connection is 0.2 and it reaches more then 0.5 when SNF is about 20 seconds.

IV. Performance Evaluation

In this section, we evaluate the performances of our protocol using NS-3 simulator [1]. We compare DHVN performances to those of Farthest_Relay, DDT, DDT with a store and forward mechanism that we called DDTSNF, and an enhancement of this later that takes into account the ability to discriminate relays based on their height and relaying capabilities that we called EDDTSNF.

A. Simulation Parameters

We conducted simulations in 3000×3000m² square area, with 36 intersections (Manhattan). In our simulations, the velocity varies from 30kms/h to 50kms/h (urban area) and the number of vehicles varies from 50 to 650. The two-ray ground propagation model was used; this model considers both the direct path and a ground reflection path and takes into account the node's height. We notice that higher is the node or the antenna, bigger is the radio coverage. Simulations were repeated with at least ten separate mobility patterns to reach a 95% confidence interval. Simulation parameters are summarized in the following table:

TABLE I
Simulation Parameters

Parameter	Value
Simulation area	3000*3000m^2
Simulation time	350 s
Road length	500 m (2 lanes)
Number of nodes	50-550
Initial position	Random
Vehicle speed	30-50 km/s
Propagation model	Two ray ground
Car height	1m (regular vehicle) - 2m (truck)
Higher nodes ratio	20%
Radio range	250m (regular vehicle) -375 m (truck)

To evaluate the performances of our protocol, we focus on two performance metrics: (i) PDR (Packet Delivery Ratio) which is the average number of packets successfully received divided by the total number of sent packets, (ii) Transmission duplication defined as the average number of transmissions of each unique message for each sender, and (iii) Reception duplication which is the average number of receptions of each unique message for each receiver.

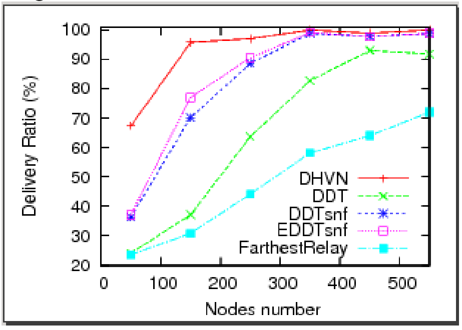
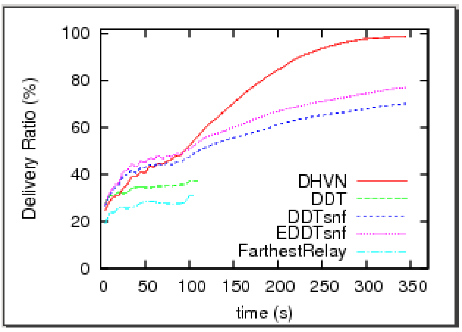
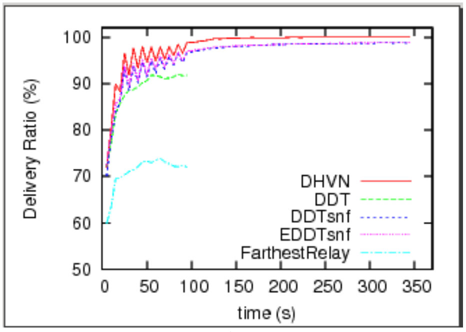


Fig. 5. PDR vs. Number of nodes.

Fig. 5 shows the PDR when varying the number of nodes from 50 to 550 (low to high density). As expected, the delivery ratio in DHVN, DDTSNF and EDDTSNF is higher than DDT or Farthest_Relay. Indeed, in both DDT and Farthest_Relay the dissemination stops at the first connectivity break. Protocols using SNF ensure continuous transmission. In low density (50 nodes) DHVN gives more than 60% of delivery ratio. This shows that DHVN is more efficient because it takes into account roads' topology and the message could be sent in all directions within an intersection. Even with SNF technique DDTSNF and EDDTSNF give less than 30% of delivery ratio. This is due to message losses especially in intersection zones where the message is often propagated in some directions only. To see that, we depict in Fig. 6 the PDR evolution versus time for 150 and 550 nodes. In both figures DDT and Farthest_Relay stop sending message after 100 seconds because each message is sent only once and it could be lost when node is alone or all of its neighbors have already received a message as previously explained. We note also that DHVN is faster than the other protocols and it can reach a higher delivery ratio very quickly. In fact, the choice of the highest relay reduces the necessary time to achieve farthest nodes in the broadcasting area.



(a)



(b)

Fig. 6. PDR vs. Time (a) 150 nodes, and (b) 550 nodes.

Fig. 7 shows the transmission duplication. Both DDT and Farthest_Relay transmit the packet exactly once since they do not have the SNF module. We notice that the average transmission in DHVN is higher. In fact, in a low-density network each vehicle sends the packet more frequently until it finds another relay. The transmission decreases when the network is dense because farthest neighbors cancel the transmission and take over the message forward. This results show a tradeoff between height delivery ratio and transmission overhead.

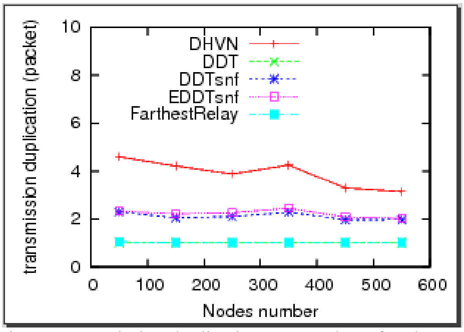


Fig. 7. Transmission duplication vs. Number of nodes.

We can see in Fig. 8 representing the reception duplication that the number of useless receptions increases when the network is dense. With DHVN, the vehicles receive more messages since messages are transmitted in all directions at the intersections.

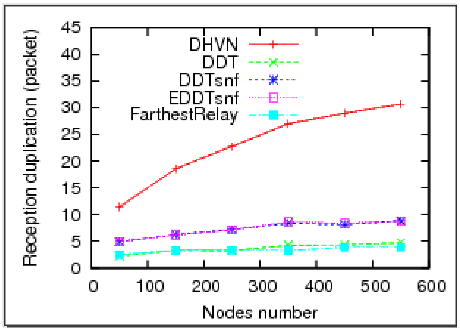


Fig. 8. Reception duplication vs. Number of nodes.

In Fig. 9, we show the delivery ratios of the five protocols as a function of velocity. We vary the speed of 300 vehicles between 30 and 130 kms/h. DHVN gives the best results whatever the speed. This is very encouraging, since we can state that DHVN can be used not only in urban environment but also on highways.

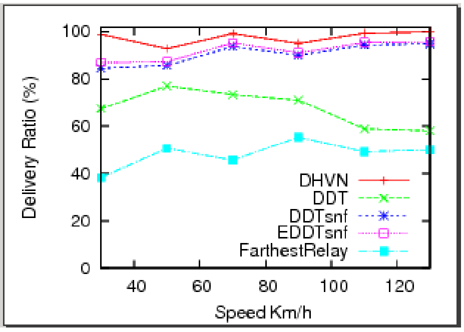


Fig. 9. PDR vs. Vehicles' speed (300 vehicles).

Fig. 10 shows the PDR when varying the ratio of higher nodes between 10% and 40% using 300 vehicles. The PDR increases when the ratio of higher nodes increases. We can observe that with 40% (respectively 20%) of vehicles with a high antenna height permits to improve the delivery ratio of DHVN that can reach 99% (respectively 90%). This is perfect for real urban scenario.

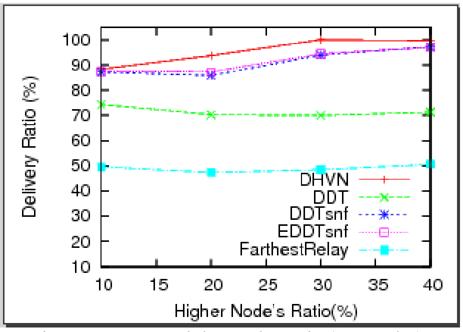


Fig. 10. PDR vs. Higher nodes ratio (300 nodes).

B. Discussions

The proposed algorithm, DHVN, requires neither prior neighbor's information nor any roadside units and it is robust in a city and a highway for any node density. Even though it is not the best one for the overhead; it solves the message losses problem and enhances the delivery ratio. Moreover, it takes into account the heterogeneity of vehicles that helps to have a best coverage.

V. CONCLUSION

In this paper, we present a new dissemination protocol DHVN dedicated for cooperative vehicular networks. In contrast to the existing solutions, DHVN considers the non-homogeneous topology and connectivity characterizing urban vehicular environment. It also takes into consideration the non-homogeneity of the vehicles in terms of communication capabilities. Simulation results show that DHVN gives the best delivery ratio in low or dense networks with an acceptable overhead.

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