Broadcasting in VANET

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***Abstract*— In this paper, we report the first complete version of a multi-hop broadcast protocol for vehicular ad hoc networks (VANET). Our results clearly show that broadcasting in VANET is very different from routing in mobile ad hoc networks (MANET) due to several reasons such as network topology, mobility patterns, demographics, traffic patterns at different times of the day, etc. These differences imply that conventional ad hoc routing protocols such as DSR and AODV will not be appropriate in VANETs for most vehicular broadcast applications. We identify three very different regimes that a vehicular broadcast protocol needs to work in: i) dense traffic regime; ii) sparse traffic regime; and iii) regular traffic regime. We build upon our previously proposed routing solutions for each regime and we show that the broadcast message can be disseminate efficiently. The proposed design of the Distributed Vehicular Broadcast (DV-CAST) protocol integrates the use of various routing solutions we have previously proposed.**

I Introduction

Broadcasting in vehicular ad hoc networks (VANET) is emerging as a critical area of research. One of the challenges posed by this problem is the confinement of the routing problem to vehicle-to-vehicle (V2V) scenarios as opposed to also utilizing the wireless infrastructure (such as cellular networks). At a fundamental level, safety and transport efficiency is a mandate for current car manufacturers and this has to be provided by the cars on the road as opposed to also using the existing wireless communications infrastructure. Such applications with this real-world constraint calls for a new routing protocol for vehicular broadcasting in VANET.

In this paper, we report the first comprehensive study on the subject whereby the extreme traffic situations such as dense traffic density, sparse traffic density, and low market penetration of cars using DSRC technology are specifically taken into account. We show that our Distributed Vehicular Broadcasting protocol can cope with all of these important considerations.

The remainder of this paper is organized as follows. Section II presents different regimes of interest in VANET that the designed broadcast protocol should be able to handle. Section III outlines the basic components of the proposed Distributed Vehicular Broadcasting (DV-CAST) protocol. Section IV discusses some practical issues related to DV-CAST and Section V summarizes the main findings of our study.

II Different Regimes for Broadcasting in VANET

Our previous research has identified three different regimes of operation in VANET: 1) Dense Traffic Regime; 2) Sparse Traffic Regime; and 3) Regular Traffic Regime. The first two of these three cases correspond to extreme scenarios. It is important to understand the characteristics of these three regimes as a good broadcast routing protocol has to be able to deal with all these three regimes. Below, we give a brief overview of these regimes based on our previous work in this area [1, 2].

A Dense Traffic Regime

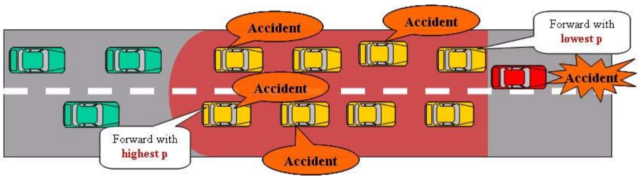
When the traffic density is above a certain value, one of the most serious problems is the choking of the shared medium by an excessive number of the same safety broadcast message by several consecutive cars. Because of the shared wireless medium, blindly broadcasting the packets may lead to frequent contention and collisions in transmission among neighboring nodes. This problem is sometimes referred to as *broadcast storm problem* [3]. While multiple solutions exist to alleviate the broadcast storm problem in a usual MANET environment [3–6], only a few solutions exist for resolving this issue in the VANET context [1, 7, 8]. In [1], we (i) explore how serious the broadcast storm is in VANET using a case study for a four-lane highway scenario; and (ii) propose three light-weight broadcast techniques; i.e., weighted p-persistence, slotted 1-persistence, and slotted p-persistence, which can provide 100% reachability in a well-connected network and up to approximately 70% reduction in the broadcast redundancy and packet loss ratio on a well-connected vehicular network. The proposed schemes are distributed and rely on GPS information (or received signal strength when the vehicle cannot receive GPS signal), but do not require any other prior knowledge about network topology.

Specifically, Figure 1 shows three distance based schemes [1]:

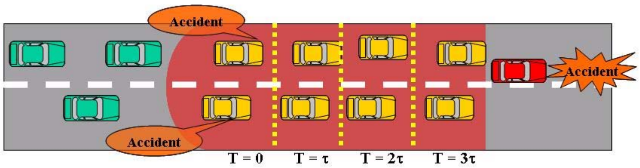
i) Weighted p-Persistence Broadcasting
ii) Slotted 1-Persistence Broadcasting
iii) p-Persistence Broadcasting

The basic broadcast techniques follow either a 1-persistence or a p-persistence rule. Despite the excessive overhead, most routing protocols designed for multi-hop ad hoc wireless networks follow the brute-force 1-persistence flooding rule which requires that all nodes rebroadcast the packet with probability 1 because of the low complexity and high packet penetration rate. Gossip-based approach, on the other hand, follows the p-persistence rule which requires that each node re-forwards with a pre-determined probability p. This approach is sometimes referred to as probabilistic flooding [9]. Figure 2 shows the main results obtained with the three schemes designed.

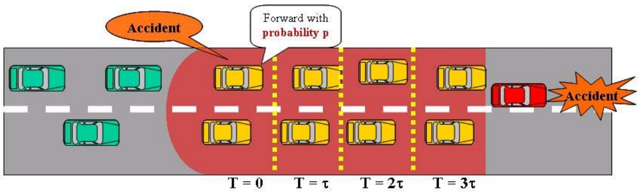
Observe that the slotted p-persistence scheme can substantially reduce the packet loss ratio at the expense of a slight increase in total delay and reduced penetration rate.



(a) Weighted p-persistence

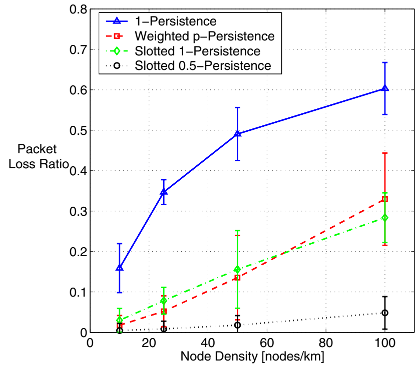


(b) Slotted 1-persistence scheme

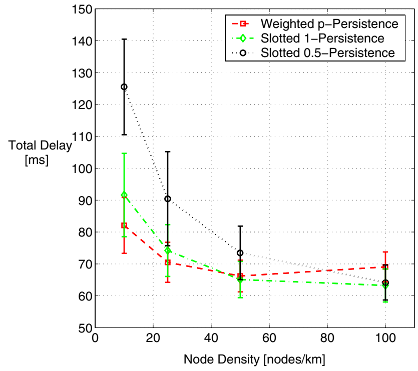


(c) Slotted p-persistence scheme.

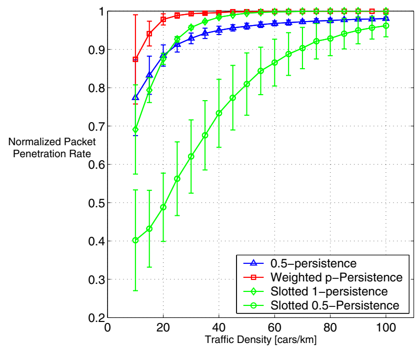
Fig. 1. Broadcast Suppression Techniques.



(a) Packet Loss Ratio in VANET.



(b) Time required to disseminate the broadcast message to nodes that are 10 km away.



(c) Normalized Packet Penetration Rate

Fig. 2. Broadcast statistics at various traffic densities. All results are shown with 95% confidence intervals.

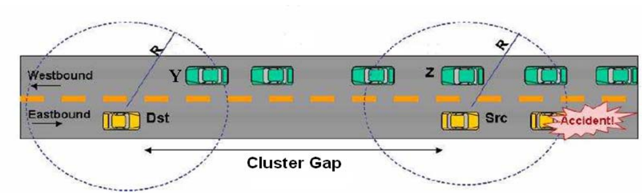
B Sparse Traffic Regime

The other extreme scenario, which is very troublesome for conventional routing protocols, is the case where there are not many vehicles on the road, as illustrated in Figure 3.

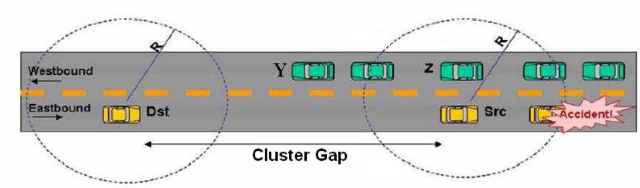
At certain times of the day (e.g., between midnight and 4 am in the morning) the traffic density might be so low that multi-hop relaying from a source (the car trying to broadcast) to the cars coming from behind might not be plausible because the target node might be out of the transmission range (relay range) of the source. To make the situation worse, there might be no cars within the transmission range of the source in the opposite lane either, see Figure 3(c). Under such circumstances, routing and broadcasting becomes a challenging task. While there are several routing techniques which address the sparsely connected nature of the mobile wireless networks, e.g., Epidemic routing [10], Single-copy [11], Multi-copy 'Spray and Wait' [12], there are only a few that considered a VANET topology [7, 8, 13]. In this paper, we propose to cope with such extreme cases via the so-called *store-carry-forward* mechanism [14]. Our results show that depending on the sparsity of vehicles or the market penetration rate of cars using Dedicated Short Range Communication (DSRC) technology [15], the network re-healing time, which captures the delay that incurs in delivering messages between disconnected vehicles, can vary from a few seconds to several minutes. This suggests that, for vehicular safety applications, a new ad hoc routing protocol will be needed as conventional ad hoc routing protocols such as DSR [16] or AODV [17]will not work with such long re-healing times. In Figure 4, we give the main results obtained via our store-carry-forward approach [2].

C Regular Traffic Regime

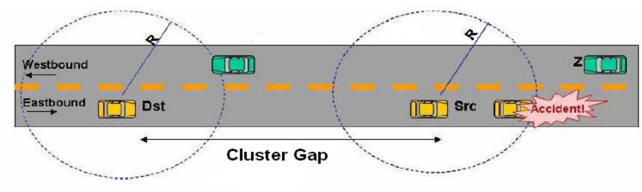
For both sparse and dense traffic scenarios previously considered, it is likely that the local connectivity experienced by each vehicle in a network would also reflect the global connectivity, e.g., a vehicle in a dense network is likely to observe a dense local topology while vehicles in a sparse network are likely to have zero or only a few neighbors or observe a sparse local topology. More specifically, all vehicles operating in these two extreme regime will observe the same local topology which also reflect the real global topology. In a regular traffic regime, however, not every vehicle see the same local topology, i.e., some may have very few neighbors while some have many neighbors. In this case, some vehicles will have to apply the broadcast suppression algorithm while



(a) Best case scenario: packet can immediately be relayed to the target vehicles via vehicles in the opposite traffic



(b) Intermediate case scenario: vehicles in the opposite direction is responsible for store-carry-forward the message back to vehicles in the message forwarding road



(c) Worst case Scenario: packet cannot immediately be relayed to vehicles in the opposite direction

Fig. 3. Illustration of the disconnected VANETs.

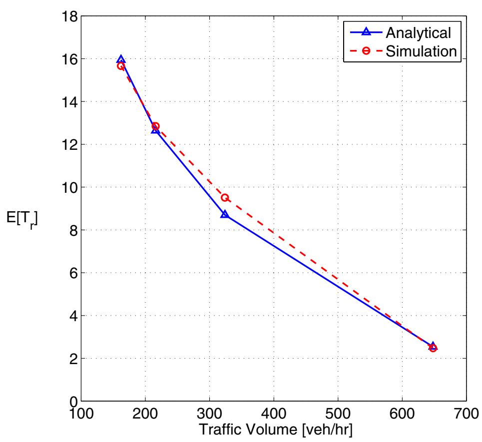


Fig. 4. Average per-gap re-healing time: Simulation results (dashed lines) and analytical results(solid lines).

some will have to store-carry-forward the message in order to preserve the network connectivity.

In the following section, we use these three fundamental traffic scenarios as our building blocks in designing a distributed vehicular broadcast protocol (DV-CAST) for VANETs.

III Distributed Vehicular Broadcast (DV-CAST) Protocol

A Design Goal

A broadcast protocol for vehicular ad hoc wireless networks should be reliable, robust, and bandwidth efficient. More specifically, the protocol should be able to distribute broadcast information to all intended recipients of the message. In addition, it should be robust against all possible traffic conditions, e.g., light traffic, moderate traffic, traffic jam. Last but not least, it should incur low overhead especially when operating in a traffic jam condition.

In designing DV-CAST protocol, the following assumptions were made. First, we assume that the infrastructure is not available in the network considered. This is a reasonable assumption as we envision that it would take years to utilize such infrastructures as automotive and telecommunication industries have to cooperate. To enable communication in VANET, we assume that each vehicle, which has a Global Positioning System (GPS) and a wireless communication device, periodically sends out beacon messages (hello messages) to its neighbors at a default frequency of 1 Hz. While periodic beaconing is an aggressive approach which is clearly not bandwidth efficient, it is a necessary mechanism for many safety applications in VANET. We, finally, assume that not every vehicle is a member of a specific VANET due to the market penetration factor, i.e., not every vehicle has a wireless communication device.

B Design Principle

We propose to use a per-hop routing based approach which uses only local connectivity information (1-hop neighbor topology) to make a routing decision. The motivation for using local connectivity in the broadcast protocol design is to ensure the maximum reachability of the broadcast message. In addition, other safety applications also rely on these beaconing messages; therefore, the local connectivity is already a given piece of information which the routing protocol can utilize. We claim that the local topology information is sufficient for proper handling of the broadcast packet.

Other information such as global topology (traffic volume/density, or a more comprehensive n-hop neighbors topology, where $n > 1$) may be useful for designing a hierarchical protocol. For example, one possible approach is to use the available global information to identify which of the three traffic regimes one is operating in and then augment that with local information that can be obtained via broadcasting periodic hello messages. The coarse information could, in principle, reduce/eliminate the use of periodic hello messages in the dense traffic regime, thus saving bandwidth. However, this approach may not be practical in the early deployment period due to the following reasons:

- Global topology information may be collected and disseminated by the existing infrastructure, e.g., Road Side Units (RSU), smart traffic lights, smart traffic cam, etc. However, deployment of these infrastructure units may not be possible since communications in VANET can take place anywhere, on any road or highway, so the area of interest in VANET could be quite large. In addition, what is more important for the protocol is the effective traffic density which is the density of the vehicles that are equipped with wireless communication devices; therefore, the traffic density as detected by these infrastructure units may not be helpful.

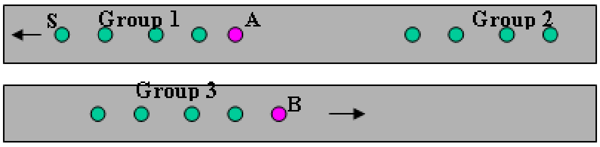


Fig. 6. Scenario 1

- Vehicles may be able to cooperatively exchange the topology information in order to estimate the traffic density. However, this approach may incur high overhead and consume a lot of bandwidth. Therefore, using global topology information might not be appropriate if smart infrastructure is not available.

C DV-CAST Protocol

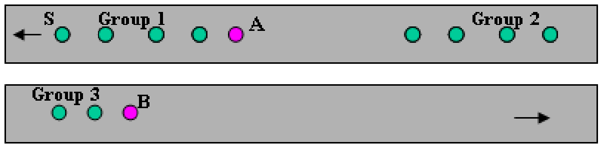
In this paper, we propose a new Distributed Vehicular Broadcast protocol known as the DV-CAST protocol that is *entirely based on the local information established by each node* (car) via the use of periodic hello messages. Figure 5 illustrates the main concept of the DV-CAST protocol where the link layer provides the network layer with the local connectivity information. Each vehicle continuously monitors its local connectivity in order to determine which state it is operating in at the time of the packet arrival. More specifically, the state is defined by the relevancy of the broadcast message to the vehicle and the provided local connectivity information. DV-CAST takes various courses of action according to the state that the vehicle is operating in. For example, a vehicle in a well-connected neighborhood should immediately apply one of the broadcast suppression back-off algorithms previously described in Section II-A when it receives the broadcast message, while different set of actions should be taken by a vehicle in a sparsely connected neighborhood.

1) Routing Parameters: The most important parameters for DV-CAST protocol are the local topology information and the Region of Interest. In particular, each vehicle should be able to (i) determine whether it is the intended recipient of the message that is moving in the same direction as the source; (ii) determine whether it is the last vehicle in the group/cluster; and (iii) determine whether it is connected to at least one vehicle in the opposite direction. These three parameters are denoted in this paper as Destination Flag (DFlg), Message Direction Connectivity (MDC), and Opposite Direction Connectivity (ODC), respectively.

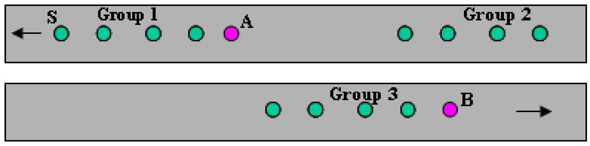
2) Routing Rules: In order to handle the broadcast message properly, we propose that each vehicle follows two basic routing rules:

i) If DFlg is set to 1, vehicle should ignore any duplicate broadcast or follow the diagram in Figure 5 if the message is received for the first time.
ii) If DFlg is set to 0, vehicle is a relay node and should follow the routing diagram.

Depending on the level of the local connectivity that the vehicle experiences, we propose three different courses of action that the vehicle should follow in order to properly handle the broadcast packet.



(a) Scenario 2.1



(b) Scenario 2.2

Fig. 7. Scenario 2

Case I: Well-Connected Neighborhood

A vehicle is said to be in well-connected neighborhood if it has at least one neighbor in the message forwarding direction (MDC = 1). Upon receiving the broadcast message, vehicle in this regime should apply one of the broadcast suppression techniques previously presented in SectionII-A. For example, if the slotted 1-persistence scheme is employed, each vehicle in this neighborhood will use the relative distance information calculated by using the source's information available in the packet header to determine the necessary back-off time suggested by the suppression scheme used, which is typically less than 100 ms. If the vehicle does not hear any rebroadcast of the same packet during this back-off period, it should rebroadcast the packet when this back-off timer expires. However, if it overhears the rebroadcast from its neighbor, it should cancel the pending rebroadcast and go back to the IDLE state. Observe that information regarding neighboring vehicles in the opposite direction is not relevant in this case. In particular, vehicles which are in a well-connected neighborhood assume that they are operating in a dense traffic regime regardless of the actual global connectivity, i.e., it is expected that all vehicles will be in a well-connected neighborhood during rush hours while only a fraction of the vehicles will be in a well-connected neighborhood under normal traffic conditions.

According to Figure 6, each vehicle in Group 1, except for A which is the last vehicle in the cluster (MDC = 0), upon receiving the broadcast message from S, will have the following flags <MDC =1, ODC = 1/0, DFlg = 1>. Vehicles in Group 3 except for B will also have similar flags, i.e., <MDC = 1, ODC = 1/0, DFlg = 0>. Each vehicle from both groups except for A & B will apply the broadcast suppression algorithm, presented in Section II-A.

Case II: Sparsely-Connected Neighborhood

A vehicle is operating in a sparse traffic regime if it is the last one in a cluster. Furthermore, a vehicle in this regime is said to be in a sparsely-connected neighborhood if there is at least one neighbor in the opposite direction as in the case of vehicles A and B in Figure 7. The parameters for these vehicle should be set to <MDC = 0, ODC = 1, DFlg = 0/1>. Upon receiving the broadcast message, these vehicles can immediately rebroadcast. However, if the vehicle is moving

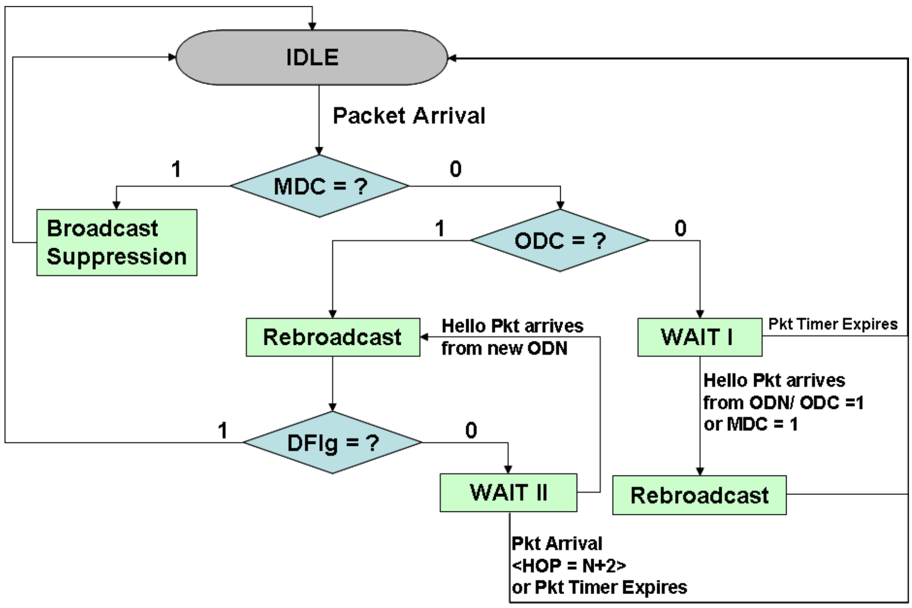


Fig. 5. Decision Tree for DV-CAST Protocol (ODN = Opposite Direction Neighbor).

in the same direction as the source, as in the case of vehicle A whose DFlg is set to 1, it can go back to an IDLE state after the rebroadcast. However, a vehicle whose DFlg is 0, as in the case of vehicle B, has to make a transition to the WAIT II state where it waits until the packet timer expires or until it can rebroadcast the packet back to the original message forwarding direction. Similar to the previous case, vehicles in a sparsely connected neighborhood assume that they are operating in a sparse traffic regime regardless of the actual global traffic condition.

In order to get a better understanding of how to handle the broadcast packet in this case, we will use the two scenarios shown in Figure 7 as an example.

- **Scenario 2.1:** A and B will hear the same broadcast, A may or may not hear the rebroadcast with greater hop count from B so it will simply rebroadcast and make a transition to the IDLE state. On the other hand, B will have to hold on to the message until it detects a new neighbor vehicle in the opposite direction or until the packet timer expires. The packet expiration time is a very important parameter for a relay node whose DFlg is set to 0 as it is the maximum time that a relay node has to hold on to the message. The value used for this parameter depends on many factors such as the maximum time the relay node is willing to store the packet, the message lifetime, or the expected time that the vehicle remains in the region of interest. Hence, the packet expiration time is typically on the order of several seconds to a few minutes. After the rebroadcast, if B comes into contact with vehicles in Group 2, B will rebroadcast and go into the WAIT II state again. This time, however, B will have to wait for an implicit acknowledgment that is the rebroadcast of the message with greater hop count and go into the IDLE state. (Note that, although the protocol can force B to go into the IDLE state immediately after it has rebroadcast to vehicles in Group 2 by keeping extra routing parameters such as the number of rebroadcast, we propose to use only three routing parameters, i.e., MDC, ODC, and DFlg, so the number of states are optimized for three parameters.) However, if the gap between Group 1 and Group 2 is very large, B will likely be out of the broadcast region and drop the packet before it reaches Group 2.
- **Scenario 2.2:** After A and B rebroadcast, they will go into the WAIT II state. Since Group 3 is connected to both Group 1 & 2, both A and B will hear a rebroadcast with greater hop count and will make a transition into the IDLE state.

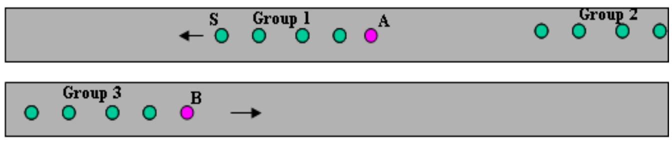


Fig. 8. Scenario 3

Case III: Totally Disconnected Neighborhood

A vehicle, operating in a sparse traffic regime, is said to be in a totally disconnected neighborhood if it has no neighbor in the message forwarding direction and is not connected to anybody in the opposite direction, i.e., MDC = ODC = 0. In this case, the disconnected vehicle, vehicle A in Figure 8, should hold on to the broadcast message until it can delegate the broadcast responsibility to a vehicle in the opposite direction or to the following vehicle or until the packet expires from the table.

According to Figure 8, A is disconnected from Group 3 and Group 2. The flags should be set to $<$MDC = 0, ODC = 0, DFlg = 1$>$. For this scenario, A will have to go to the WAIT I state and wait for the hello packet from vehicles in Group

3 or from vehicle in Group 2 who may have caught up with Group 1 while *A* is in the WAIT I state. Once *B* moves into *A*'s range, the ODC flag of *A* will be changed to 1 and *A* will immediately rebroadcast. Vehicle *B*, according to Figure 8, may or may not have heard the broadcast message when it receives the rebroadcast from *A*. However, since DFlg of *B* is 0, it will always help to relay the message. So when *B* receives the broadcast message from *A* it will have the following flags <MDC = 0, ODC = 1, DFlg = 0> which is the same setting as in Scenario 2.1.

Note that, it is likely that vehicles in a dense traffic regime will only be in a well-connected neighborhood and every vehicle will have to use the broadcast suppression mechanism while most vehicles in a sparse traffic regime will either be in a sparsely-connected or totally disconnected neighborhoods so they will have to resort to store-carry-forward mechanism. However, vehicles operating in a normal traffic regime may be in any of these three neighborhoods, so each vehicle in this traffic regime can take any of the three different actions to handle the broadcast packet.

IV Discussion

Perhaps one of the major challenges in designing a broadcast protocol such as DV-CAST is the uncertainty of the VANET topology. Without the map information, each vehicle has to at least be able to distinguish the relative locations of the 1-hop neighbors, e.g., neighbors can either be moving in the same or opposite direction and neighbors moving in the same direction can either be in the leading group or following group. For a typical highway with small curvature, it is adequate to simply use the GPS information; i.e., latitude, longitude, and heading, to categorize neighbors into these three groups of interest. However, additional information such as GPS trails (history of GPS information) may be needed in irregular topologies such as highway exit or urban areas. This topic is currently being investigated.

Another important factor that could cause the protocol to fail is the accuracy of the local topology information. While the current DV-CAST protocol design assumes that each vehicle can accurately detect the local connectivity, in a real VANET this assumption may not be always valid as there could be many uncontrollable factors that could cause the neighbor detection mechanism to fail, e.g., a vehicle may not be able to receive GPS signal in certain areas, hello message sent from certain neighbors may collide with other messages especially in a dense traffic scenario, or some vehicles may be selfish and refuse to rebroadcast the message. Hence, it is necessary to consider fail-safe mechanisms when implementing the actual protocol. We are currently looking into such enhancements.

While the DV-CAST protocol is designed to use only three parameters, i.e., MDC, ODC, and DFlg, to handle the broadcast packet, there are many optimization techniques one could apply to the current protocol design in order to handle the broadcast more efficiently, e.g., by keeping additional routing parameters so that each vehicle does not broadcast the message unnecessarily. Another extreme optimization technique is to keep a full list of neighbors instead of using a flag so that the disconnected vehicle can delegate the relaying responsibility to one or certain group of vehicles by unicasting or multicasting. We are currently studying the network performance of DV-CAST under realistic conditions via simulations. The simulation results could potentially indicate other loop holes that one has to deal with.

V Conclusions

In this paper, we have proposed a new Distributed Vehicular Broadcasting protocol (DV-CAST) design for safety and transport efficiency applications in VANET. The designed protocol addresses how to deal with extreme situations such as dense traffic conditions during rush hours, sparse traffic during certain hours of the day (e.g., midnight to 4 am in the morning), and low market penetration rate of cars using DSRC technology. The proposed DV-CAST protocol is fully distributed and relies on the local information provided by one-hop neighbors via periodic hello messages.

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