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A directional data dissemination protocol for vehicular environments ☆

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ABSTRACT

This paper presents a simple and robust dissemination protocol that efficiently deals with data dissemination in both dense and sparse vehicular networks. Our goal is to address highway scenarios where vehicles equipped with sensors detect an event, e.g., a hazard and broadcast an event message to a specific direction of interest. In order to deal with broadcast communication under diverse network densities, we design a dissemination protocol in such a way that: (i) it prevents the so-called broadcast storm problem in dense networks by employing an optimized broadcast suppression technique; and (ii) it efficiently deals with disconnected networks by relying on the store-carry-forward communication model. The novelty of the protocol lies in its simplicity and robustness. Simplicity is achieved by only considering two states (i.e., cluster *tail* and *non-tail*) for vehicles. Furthermore, vehicles in both directions help disseminating messages in a seamlessly manner, without resorting to different operation modes for each direction. Robustness is achieved by assigning message delivery responsibility to multiple vehicles in sparse networks. Our simulation results show that our protocol achieves higher delivery ratio and higher robustness when compared with DV-CAST under diverse road scenarios.

1. Introduction

Vehicular Ad-hoc Networks (VANETs) have gained considerable attention in the past few years due to their promising applicability with regard to safety, transport efficiency, and information/entertainment [1]. In particular, vehicular networks enable the opportunistic sensing of road environments that range from traffic flow and pollution monitoring to safety warning services [2]. Because modern vehicles are equipped with powerful processing units such networks, referred to as vehicular sensor networks (VSNs), are not typically affected by energy constraints and, therefore, differ considerably from traditional wireless sensor networks (WSNs).

For many of these applications, the data acquired by sensors, e.g., crash detection data, must be broadcast (disseminated) to all vehicles nearby. Because these events might not directly affect all vehicles within the event perimeter, broadcast messages can be propagated towards a specific direction such as to vehicles that are in fact approaching the dangerous area. In this paper, we consider the problem of coordinating these broadcast messages to a specific direction in a reliably, timely, and efficiently manner using vehicle-to-vehicle communications. We present a dissemination protocol which assumes no information available about the road topology. Therefore, in this work we focus on highway scenarios, where simple long bidirectional roads are present. For more complex topologies, such as the ones found in urban environments, geographical mapping information can be used to enhance our approach in future work.

In order to deal with broadcast communication, different dissemination strategies should be defined according to the current network situation. In dense networks, the number of broadcasts must be minimized to avoid excessive redundancy, contention, and collision rates [3]. These undesired factors collectively are referred to as the *broadcast storm problem*. The minimization of these factors can be achieved by means of *broadcast suppression techniques* [4].

In sparse networks, on the other hand, the *store-carry-forward* communication model can take advantage of the mobility of nodes to store and transfer messages when nodes are geographically separated. This approach is commonly put in practice in delay tolerant/opportunistic networks [5,6]. In this type of network, vehicles assess the best available opportunities of connectivity for data dissemination and make decisions solely based on current knowledge. For instance, at the moment of an encounter of

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multiple vehicles, each vehicle carrying data evaluates the probability that other vehicles would lead this data to its final destination or geographical region of interest. For this assessment, available knowledge such as the vehicle's direction or even the complete route of a vehicle set in a navigation system is taken in account. In this paper, we concentrate on exploiting the movement pattern of vehicles in one direction to cope with separate vehicle clusters in the other direction as motivated in [7,8].

The contribution of this work lies in combining an optimized broadcast suppression technique with the store-carry-forward model in a single dissemination protocol called the simple and robust dissemination (SRD) protocol. Such protocol operates seamlessly in the network layer in both dense and sparse networks. This paper extends our previous work published in [9] with a much richer detailed explanation of the protocol and with a complete performance evaluation which includes several new aspects such as the direct comparison with DV-CAST [10]; up to best of our knowledge, the only protocol that also focus on directional broadcasting in both dense and sparse highways. By means of simulations under diverse highway scenarios, we show that SRD presents better overall performance in terms of delivery ratio and robustness when compared with DV-CAST.

The remainder of this paper is organized as follows. Section 2 provides an overview and brief comparison between SRD and other proposals with respect to suppression techniques and protocols that deal with sparse networks. Next, Section 3 describes the SRD protocol in detail. Section 4 describes the performance evaluation of the protocol carried out by means of simulations. Finally, Section 5 concludes this paper and outlines our future directions.

2. Related work

Various solutions for VANETs have been proposed to cope with message dissemination under different traffic conditions. In dense scenarios, *suppression* techniques have been proposed to address the so-called broadcast storm problem. For a given broadcast message, the solution of this problem consists in finding the minimum set of nodes capable of reaching all other nodes in the network. If only nodes in this set broadcast this message, redundancy is kept to a minimum. In the context of mobile Ad-Hoc networks (MANETs) several solutions to address this problem are proposed, e.g., [11]. However, these solutions are generally not optimal for VANET scenarios, due to basic dissimilarities with MANETs. First, the mobility of nodes in VANETs is constrained to roads, so it is possible to employ simpler methods to select nodes that should broadcast a given message. In addition, solutions for VANETs should cope with much higher speeds when compared to MANETs.

Unlike MANETs, only a few suppression techniques have been proposed specifically for VANETs. In [4], three broadcast suppression techniques are presented to be employed in the network layer. Among these three techniques, Slotted 1-Persistence has achieved the best performance in terms of reducing the number of unnecessary broadcasts while still achieving a low end-to-end delay and high delivery ratio. This technique is time-based and non-probabilistic. Given a fixed number of time slots, the most distant vehicles in the message direction from the source vehicle, i.e., from where the message has been originated, will be given the earliest time slot to rebroadcast. Vehicles assigned to other time slots would then have time to cancel their transmissions upon the receipt of an echo. This would be an indication that the information has already been disseminated and redundant rebroadcasts are *suppressed*.

However, the Slotted 1-Persistence technique suffers from a synchronization problem [12,13] that can occur when multiple vehicles are assigned to a single time slot and start their transmissions simultaneously. This results in a substantial deterioration with respect to delivery ratio due to a higher number of collisions. In this paper, we tackle this problem by proposing the *Optimized Slotted 1-Persistence* technique (described in Section 3.3).

The use of vehicles moving in the opposite direction to help in message dissemination for sparse networks has been previously studied in [14,15,7,16,17]. In [14], three scenarios are considered: vehicles moving in the same or the opposite direction of the originator of the message and vehicles moving in both directions. Simulation results demonstrate that the use of vehicles moving in opposite directions improves the dissemination performance in many different scenarios. The directional propagation protocol [15] allows directional propagation of messages from a given point of origin. It requires the adoption of a cluster creation/maintenance mechanism and differentiates between inter and intra cluster communication. Further evaluation of this protocol in [7] has shown that vehicle mobility can be used to improve message propagation in scenarios in which conventional MANET protocols would fail due to the lack of end-to-end connectivity. The abiding geocast, described in [17], disseminates accident or congestion information to every vehicle passing through a warning zone during the event lifetime.

There is extensive work in the area of delay tolerant networks (DTN) and opportunistic networks for communication in disconnected networks. The *Epidemic routing* [18] uses flooding to disseminate messages through the network. In this approach nodes exchange data as soon as new neighbors are discovered. The *spray routing* [19] generates only a small number of message copies in order to ensure that the number of transmissions are small and controlled. In [20], moving relay nodes, referred to as *data mules*, are used to carry the messages to their destination. In the context of pocket switched networks (PSNs), where the nodes are devices carried by people, the *BUBBLE* algorithm is proposed [21]. It takes into account people's social relationships to select the nodes that can best relay messages. Once again, these approaches were designed assuming a different mobility model than the one present in VANETs, where the mobility of vehicles is constrained to single or multiple roads and usually follow well-defined rules, and for this reason they may not be suitable in this context. To the best of our knowledge, only two works apply the *store-carry-forward* mechanism for message dissemination in VANETs: the Distributed Vehicular Broadcast (DV-CAST) protocol [10] and the acknowledged parameterless broadcast in static to highly mobile (ackPBSM) [22].

The goal of the DV-CAST protocol is to adapt to different traffic densities, e.g., light traffic, moderate traffic, or traffic jam, while introducing a low overhead in high density situations and managing communication gaps in low density situations. Unlike in our protocol, DV-CAST relies on the periodic exchange of *hello messages* between all communicating vehicles. Especially in dense and dynamic networks, if not coordinated properly, hello messages might increase collision and contention, thus wasting bandwidth. Although our protocol also requires the exchange of periodic messages, a suppression technique is employed to prevent the so-called broadcast storm problem and to reduce the number of broadcasts. Our protocol also avoids the dependency on a single vehicle when bridging radio gaps in the network. All vehicles in the range of the vehicle positioned at the tail of a cluster act as *backup vehicles*, thus increasing robustness. Moreover, in [22] the DV-CAST protocol is reported to have a low reliability. This can be partially explained by unforeseen situations such as overtaking while determining the current traffic density. As in our protocol, a vehicle simply needs to determine whether it is the tail in a message direction, it does not suffer from this problem.

The ackPBSM protocol relies on the use of connected dominating Sets (CDS) to perform the broadcast. Similarly to DV-CAST,