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Using topology and neighbor information to overcome adverse vehicle density conditions

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ABSTRACT

Vehicular networks supporting cooperative driving on the road have attracted much attention due to the plethora of new possibilities they offer to modern Intelligent Transportation Systems. However, research works regarding vehicular networks usually obviate assessing their proposals in scenarios including adverse vehicle densities, i.e., density values that significantly differ from the average values, despite such densities can be quite common in real urban environments (e.g. traffic jams). In this paper, we study the effect of these hostile conditions on the performance of different schemes providing warning message dissemination. The goal of these schemes is to maximize message delivery effectiveness, something difficult to achieve in adverse density scenarios. In addition, we propose the *Neighbor Store and Forward* (NSF) scheme, designed to be used under low density conditions, and the *Nearest Junction Located* (NJL) scheme, specially developed for high density conditions. Simulation results demonstrate that our proposals are able to outperform existing warning message dissemination schemes in urban environments under adverse vehicle density conditions. In particular, NSF reduces the warning notification time in low vehicle density scenarios, while increasing up to 23.3% the percentage of informed vehicles. As for high vehicle density conditions, NJL is able to inform the same percentage of vehicles than other existing approaches, while reducing the number of messages up to 46.73%.

1. Introduction

Modern Intelligent Transportation Systems (ITS) are being propelled by the development and adoption of wireless telecommunications and computing technologies, thereby allowing our roads and highways to be both safer and more efficient transportation platforms.

Vehicular ad hoc Networks (VANETs) are wireless communication networks which support cooperative driving among vehicles on the road. Vehicles act as communication nodes and relays, forming dynamic vehicular networks together with other nearby vehicles (Ng and Waller, 2010; Santa et al., 2010). VANETs have particular features such as: distributed processing and organized networking, a large number of nodes, the distribution and the speed of these nodes, a constrained

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but highly variable network topology, variable communication conditions and mobility patterns, signal transmissions blocked by buildings, frequent partitioning due to the high mobility, and no significant power constraints.

The specific characteristics of VANETs favor the development of attractive and challenging services and applications, including road safety, traffic flow management, road status monitoring, environmental protection, and mobile infotainment (Jia et al., 2013; Paula et al., 2011; Zhou et al., 2011). In this work we focus on traffic safety and efficient warning message dissemination, where the main goal is to reduce the latency while increasing the accuracy of the information received by nearby vehicles when a dangerous situation occurs.

In a VANET, any vehicle detecting an abnormal situation on the road (i.e. accident, slippery road, etc.) starts notifying the anomaly to nearby vehicles to rapidly spread the information in a short period of time. Hence, broadcasting warning messages is of utmost importance to alert nearby vehicles. However, this dissemination is strongly affected by: (i) the signal attenuation due to the distance between the sender and receiver, (ii) the effect of obstacles on signal transmission (very usual in urban areas, e.g., due to buildings), and (iii) the instantaneous surrounding vehicle density.

Regarding (i) and (ii), the topology of the roadmap is an important factor that affects the average distance between the sender and the receiver, as well as the different obstacles present in the scenario. As for (iii), the warning message propagation scheme should be aware of the vehicle density, since lower densities can provoke message losses due to reduced communication capabilities, whereas higher densities may lead to reduced message delivery effectiveness due to serious redundancy, contention, and massive packet collisions caused by simultaneous forwarding, usually known as broadcast storm (Tseng et al., 2002).

So far, several authors have proposed different dissemination schemes to mitigate broadcast storms (Bi et al., 2010; Wisitpongphan et al., 2007; Soares et al., 2014; Suriyapaibonwattana and Pomavalai, 2008; Tseng et al., 2002). However, all of these schemes consider free space environments where no blocking obstacles are considered at all. They have not addressed the impact of buildings and other urban obstacles on the wireless signal propagation in realistic urban scenarios. The consequences derived from those incomplete analyses can be observed when their performance is tested in urban topologies, showing that they are unable to choose suitable relaying vehicles, or proving to be too restrictive to achieve an efficient message dissemination (Fogue et al., 2012b; Soares et al., 2011).

In this paper, we study the performance of typical broadcast dissemination schemes under hostile density conditions, i.e., vehicle densities that significantly differ from typical values in vehicular environments, and which are especially adverse for message dissemination. We consider that adapting the dissemination policy to the specific environment, accounting for the current vehicular density as well as for the scenario where the vehicles are located, can be beneficial in order to reduce broadcast storm related problems, and also to increase the efficiency of the warning message dissemination process. Based on this analysis, we propose both the *Neighbor Store and Forward* (NSF), scheme designed to be used under low density conditions, as well as the *Nearest Junction Located* (NJL) scheme, which was specially developed for high density conditions. Our main goal is to maximize the message delivery effectiveness, something difficult to achieve under adverse conditions.

The paper is organized as follows. Section 2 reviews existing dissemination schemes related to our proposal. In Section 3 we introduce our proposed schemes, i.e., the NSF and the NJL approaches. Section 4 shows the simulation environment used to validate our proposed algorithms. Section 5 presents and discusses the obtained results under very low and very high vehicle density scenarios. Finally, Section 6 presents the main conclusions drawn from this work.

2. Related work

Current research on vehicular networks usually focuses on analyzing scenarios representing common situations characterized by average density values. However, situations with very low or very high vehicle densities are often ignored, whereas they are very common in real vehicular environments. For example, outskirts or suburban areas usually experience density values below 25 vehicles/km^2, whereas traffic jams that appear in large cities present densities above 300 vehicles/km^2. We consider these scenarios as hostile conditions for vehicular networks, since the efficiency of warning message dissemination processes is noticeably reduced under these circumstances.

In this section we introduce some of the most relevant existing proposals related to message dissemination in vehicular networks. Before proposing new dissemination schemes specially suitable for adverse density conditions, we are going to analyze the performance of existing broadcast schemes for VANETs under these conditions, accounting for both low and high vehicle densities. Since the challenges to face in each situation are radically different, a separate study could be beneficial to maximize the performance of the message dissemination system.

2.1. Low density conditions

Vehicular scenarios including very low vehicle densities are frequently found in highways (Liu et al., 2012), and especially, in residential, rural, and outskirt traffic areas. The main goal when developing an emergency message dissemination system is to inform as many vehicles as possible in a short time period. Additionally, maintaining a low amount of wireless traffic is desirable to avoid the mentioned broadcast storm problem. When the density of vehicles is low, the relative importance of the number of messages received per vehicle is reduced, since the probability of overloading the channel with messages exchanged by just a few vehicles in minimal. Hence, suitable schemes for these situations should focus on forwarding