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A fast, reliable and lightweight distributed dissemination protocol for safety messages in Urban Vehicular Networks

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ABSTRACT

It is foreseeable that in the few upcoming years, real time traffic information, including road incidents notifications, will be collected and disseminated by mobile vehicles, thanks to their plethora of embedded sensors. Each vehicle can thus actively participate in sharing the collected information with the other peers forming an infrastructure-less self-organising network of vehicles. However, the fast development of applications in ITS field may result in an excessive load on such a network; therefore an efficient use of the available bandwidth is highly required. Not only should the size of the data inserted in the network be properly controlled, but also the extent of each message should be accurately defined. In this paper, we propose a distributed dissemination protocol for safety messages in urban areas, dubbed “Road-Casting Protocol (RCP)”, which is based on a novel cooperative forwarding mechanism. Moreover, an accurate definition of the Region of Interest (RoI) (i.e. the geographical scope) of each broadcasted safety message is also devised to ensure better control of the network load. We have evaluated the efficiency of the RCP along with the proposed RoI definition using realistic simulations, based on an accurate propagation loss model for urban vehicular ad hoc network communications, and the obtained results show a substantial improvement, compared to state of the art schemes, in terms of enhanced packet delivery ratio up to higher than 95%, lower end-to-end delay and reduced network load.

1. Introduction

Cities generate an enormous amount of data everyday. The efficient use of this information promises to revolutionize our daily lives, thanks to the “Ubiquitous Intelligence”. In fact, computers, sensors, microchips, digital networks and other electronic systems will participate in the near future in the democratization of the ubiquitous computing, that is to say, the fusion of the virtual and the real worlds to create environments called “Intelligent” which can offer a multitude of highly available services to their end users. One typical example of these applications is the Intelligent Transportation Systems (ITS) which main aims are (i) improving safety in transportation, (ii) increasing the efficiency of transportation systems with a more efficient management of the road infrastructure, and (iii) improving user comfort by providing a multitude of information services, decision support, guidance, and Internet access. All this with the objective of integrating the transportation in a sustainable development policy: ranging from reducing greenhouse gas emissions, to optimising the maintenance of the road infrastructure. Such applications are made possible with the emergence of a new type of wireless networks: The Vehicular Ad Hoc Networks (VANETs).

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The most promising amongst these applications is safety in transportation, in which the drivers should be notified early in advance about potential hazards on the road to ensure faster reaction to avoid them, leading to time saving with reduced money and lives losses. According to some studies published in [1], 60% of accidents could be avoided if drivers were provided with a warning half a second before the moment of collision. However, reaching this objective might not be an easy task to accomplish. In fact, the critical nature of safety applications requires that all emergency messages reach their destinations within a short delay (i.e. short latency), and under high communication reliability conditions compared to other application classes. Spreading an emergency message in VANETs is a cooperative process between vehicles. If not well designed, this process also called broadcasting, usually leads to an excessive load on the shared radio channel, especially in highly dense scenarios where high packets collision and lower reception rates are most likely to be observed. One additional issue where broadcasting an emergency message is the narrow communication medium. This latter, located around the frequency band of 5.9 GHz, is expected to carry a large spectrum of growing mobile distributed applications in the near future. This might weigh heavily on the limited resource reserved to this end as more than one vehicle can attempt to access it simultaneously.

The ETSI standard defines five radio channels in Europe [2] for inter-vehicular communications, and seven channels in USA [3]; including one control channel (CCH) for both standards, which is reserved for both periodic beacons and the exchange of emergency information. Each radio channel is 10 MHz wide.

In order to allocate more bandwidth for emergency messages transmissions, a multitude of solutions have been proposed to control the load of beacons on the shared CCH, which can mainly fall under one of the two categories: the first one focuses on reducing their transmission rates in highly congested scenarios while the second category proposes to adapt the transmission power of the beacons' senders. In 2011, ETSI TS released a Technical Specification namely DCC [4] (the Decentralised Congestion Control), which combines different techniques to control the load generated by beacons on the radio channel. We refer the reader to [5] for further information about DCC. As opposed to these approaches, we focus in this work on designing a novel technique that fulfils the requirements of safety messages dissemination regardless of the employed beacon transmission rate and power. Note that beacons transmission rate and power control is out of the scope of this work. The impact of beacons frequency generation and their transmission range on the performance of our dissemination protocol is also not considered in this work.

One of the main criteria that determine the efficiency of dissemination protocols in VANETs is the appropriate selection of the next forwarder of an emergency message [6]. If not carefully selected, the next forwarder could have received corrupted information and might introduce further errors in the broadcast message [7], could be in a high density area raising the probability of collisions in case it further forwards the emergency message, and thus the loss probability of the disseminated packet [8], or might have a restricted number of reachable neighbour vehicles and therefore limiting the message reachability and minimising its benefits [9]. In several existing protocols, the decisive element for the next forwarder vehicle selection is the distance: the furthest the receiver is from the sender, the more chances it gets to be selected as the next forwarder. This approach reduces the number of intermediate hops, which consequently lower the end-to-end delay. However, it is well known that the quality of the communication link drops with longer transmissions, therefore more attention should be paid to this key parameter in order to reduce the risk of safety messages corruption. An alternative solution would be to choose a closer receiver as a next forwarder instead of the furthest one. In this case, the sender–receiver distance becomes shorter, requiring the safety message to hop in more intermediate transmitters and resulting in a higher end-to-end delay.

In addition, a single vehicle is usually selected to rebroadcast the safety message in most of the existing solutions. In the absence of a proper packet loss recovery mechanism especially in standards like DSRC WAVE [3] and ETSI TS G5 [2], a simple packet collision could lead to the permanent loss of the information contained in it before it reaches its destination. This effect can be amplified in urban areas where the roads are surrounded by buildings shadowing the signals [10], and therefore considerably limiting the transmissions behind the buildings and around the corners [11].

In this paper, we tackle the problem of safety messages dissemination in Urban Vehicular Networks. In our previous work [12] we proposed a protocol that operates in the Medium Access Control layer, which deals with the network overload by controlling the number of retransmissions of each emergency message. In this work, we extend the protocol to a cross-layer solution that also controls the size of emergency messages as well as their extent, in addition to their number of retransmissions. Our new solution addresses the problem of the network overload by considering two main aspects: the first one, which is an enhancement of our previous work [12] consists of (i) selecting a set of forwarders with regard to two parameters: the distance between the sender and the forwarder taking into account the relative position of the receiver from the junction and the estimated transmission range; and the link quality including the channel quality, the vehicle mobility and the non-line of sight conditions; and the second aspect, which represent the novelty of this work, focuses on (ii) introducing a novel distributed way to accurately define the effective Region of Interest (RoI) of an emergency message based on the connectivity of the road map graph. The enhancements in the first aspect (forwarding mechanism) consist of a new probability assignment function that takes into account new parameters like the distribution of vehicles with regard to their locations. For example, it is expected that a higher density will be observed in intersections.

We argue that a precise definition of the RoI for a safety message is very important to limit the unnecessary load on the communication network, as this will only spread the information in the area where vehicles need it, freeing