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Analysis of a receiver-based reliable broadcast approach for vehicular networks

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ABSTRACT

The Intelligent Transportation Systems concept provides the ground to enable a wide range of applications to improve traffic safety and efficiency. Innovative communication systems must be proposed taking into account, on the one hand, unstable characteristics of vehicular communications and, on the other hand, different requirements of applications. In this paper a reliable (geo-)broadcasting scheme for vehicular ad-hoc networks is proposed and analyzed. This receiver-based technique aims at fulfilling the received message integrity yet keeping the overhead at a reasonably low level. The results are compared to simulation studies carried out in the Network Simulator-3 (NS-3) simulation environment demonstrating good agreement with each other. The analysis shows that in a single-hop scenario, receiver-based reliable broadcasting can provide good reliability, while giving very little overhead for high number of receivers.

1. Introduction

Forwarding and transport protocols are among the main design principles of vehicular communication systems. Forwarding of data packets, in conjunction with a routing protocol, can be classified into four types in the vehicular communication domain [1]. They are Geographical Unicast (i.e., direct or multi-hop unidirectional transport of data from a single node to a single node using geographic addresses of vehicles), Topologically-Scoped Broadcast (TSB) (i.e., transport of data packets from a single node to all nodes in the coverage scope of a vehicular network), Geographical Broadcast (i.e., transport of data packets from a single node to all nodes in a geographical region of interest), and Geographical Anycast (i.e., transport of data packets from a single node to any of the nodes in a geographical region of interest) [1].

The transport protocol of a vehicular communication system must meet application requirements, which, in turn, affects its design principles [1]. In our study, we consider reliability as the one relevant to our approach. Reliability refers to assuring that a message has reached the highest possible number of intended receivers. Due to the inherently unreliable nature of vehicular environments, it is very challenging to design an end-to-end reliable (geo-)broadcast protocol guarantying delivery of packets to all intended receivers of a vehicular network. For instance, lack of a couple of packets from the set of packets constituting big messages such as maps, at the receiver-side, makes the whole message useless.

Providing end-to-end reliable delivery for (geo-)broadcast is an open area of research. In this paper, we describe a novel receiver-based end-to-end reliable protocol in the context of geographically scoped broadcast in vehicular networks. According to this scheme, every packet, as a part of a

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message, is marked with a sequence number, in an increasing order. By sequence checking, the missing packets of a message are detected at the receiver-side and requested afterwards from the neighbors. Those neighbors having these packets in possession reply by broadcasting them. In order to minimize the effect of collisions as a result of concurrent requests and replies, a back-off timer-based policy is introduced. The proposed approach does not target a specific application but could be fitly applied in scenarios featuring large (e.g., maps) and small (e.g., regular awareness) sized messages.

The main contributions of this paper are as follows: (i) we extend the end-to-end (geo-)broadcast reliability assurance mechanism, originally proposed in the framework of the MOBILITY 2.0 FP7 project [2], (ii) we propose an analytical model for performance evaluation of the functionality of the proposed protocol and validate it using the NS-3 network simulator [14], (iii) we derive system-oriented performance measures, with a significantly extended set of results, compared to the first version of this work [7], which has been published in IEEE Vehicular Networking Conference 2014 (VNC).

The rest of this paper is organized as follows. Section 2 provides a brief account of related work. Section 3 introduces the reliable (geo-)broadcast approach. We develop the analytical model of the protocol in Section 4. In Section 5 we first validate the model using NS-3 simulations and then numerically study the protocol performance in detail. Conclusions are drawn in the last section.

2. Related work

In general, (geo-)broadcasting reliability approaches could be divided into two main categories as multi-hop and one-hop and further into sender-based (i.e., the recovery action is initiated by the sender such as regular repetitions, also known as implicit recovery) and receiver-based (i.e., the recovery action is initiated by the receiver, e.g. protocols with negative acknowledgments known as explicit recovery) approaches. Here, we refer to those mechanisms and protocols related to our approach.

In [10] overhearing of rebroadcasted messages is considered as an implicit acknowledgement for the sender and all the vehicles with pending rebroadcasts. Besides considering rebroadcast overhearing as implicit acknowledging, in Preferred and Contention Based Forwarding (PCBF) [13] if the most recent forwarder hears the rebroadcast of a packet, it sends an explicit acknowledgement to the former forwarder to stop further unnecessary rebroadcasts. Inter-Vehicle Geocast (IVG) [4] and Urban Vehicular-broadCAST (UV-CAST) [18], both are overhearing based suppression schemes with rebroadcast back-off timers, inversely proportional to the distance between the vehicles and the sender, to ensure longer packet traverse distances. Such schemes in general improve hop-by-hop and not end-to-end traverse reliability at the cost of increased overhead and redundancy.

Reliable Vehicular Geo-broadcast (RVG) [9] is based on two schemes as Slotted Restricted Mobility Based (SRMB) scheme and the Pseudo-ACK (PACK) scheme. While SRMB is responsible for data dissemination over a specified distance, PACK assures multi-hop dissemination reliability by interpreting overheard rebroadcasts as a measure of successful transmission. When the Neighbor Elimination Scheme (NES) [17] and the multipoint relaying [12] scheme of SRMB fail, PACK scheme detects unacknowledged links and repeats forwarding. In [11] besides the distance between the current receiver and the previous forwarder, the number of the local copies of the message at each receiving vehicle, is considered to take the rebroadcast decision. This approach is based on acknowledging the received messages to assure reliable delivery by indexing the copy of the messages. In [16] an end-to-end geocast acknowledgement scheme is proposed, in which individual acknowledgements are accumulated into larger messages in an aggregator. The acknowledgement is later sent to the source using a sink tree and position update schemes in order to find the path back towards the source. Acknowledged Broadcast from Static to Highly Mobile (ABSM) [15] approach is based on the Connected Dominant Set (CDS) scheme [17] and NES for reliable data dissemination. Vehicles possessing the message of interest set a back-off timer, such that the vehicles in the CDS choose a shorter back-off timer, and rebroadcast it upon timer expiration if discovering their neighborhood is not fully covered. Identifiers of the recently received messages are included in beacons as acknowledgements. In Adaptive and Reliable Broadcast (ARB) [21], each sender sets a receive acknowledgement window, which is divided into many adaptive slots proportional to the number of neighbors. The retransmission will be started if any acknowledgement from a neighbor in the table of neighbors is missing upon expiration of the acknowledgement window. Modified Hybrid Automatic Repeat reQuest-Symbol Combining (MHARQ-SC) [5] is an ACK-based approach such that a couple of packets to be transmitted are combined at first based on an SC algorithm and then transmitted to the intended receivers. It is assumed to deploy an error detection code at the receiver end able to detect any loss pattern and send a negative ACK to the sender side, otherwise a positive ACK will be sent.

Geocast routing protocol in SUb-Zone of relevance (GeoSUZ) [3] proposes to divide the geobroadcast target area into sub-areas and to use different message dissemination techniques in each of them to enhance reliability. Still, end-to-end transfer may not be satisfied. SmartGeocast [20] encompasses two phases as initialization and maintenance. The latter is considered for reliability improvement by keeping rebroadcasting at regular time intervals, within a smaller area than the target area to be less redundant and cost-efficient. As a result, this approach fails to guarantee end-to-end reliability for all the intended receivers. The approach in [19] proposed XOR coding for loss recovery in vehicular communications such that after original transmission, instead of repeating the packet transmission for a couple of times, the sender XORs its packet with other packets received from other vehicles and repeatedly transmits the XORed packet, while there is no explicit information from the receiver side for such retransmissions.

Summarizing the (geo-)broadcast reliability solutions, sender-based mechanisms cannot provide delivery assurance, as they do not rely on explicit knowledge from the receiver-side. While, receiver-based approaches are mostly ack-based and overload the network with many acknowledgement packets. In this work, a receiver-based approach is described for one-hop (geo-)broadcast, in which