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Opportunistic Clusters Selection in a Reliable Enhanced Broadcast Protocol for Vehicular Ad hoc Networks

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***Abstract*—This paper investigates a novel solution for efficiently broadcasting in vehicular networks. In high congested traffic scenarios, one of the most serious problems is the increase of packet collisions and medium contentions among vehicles which attempt to communicate. The effect results in a very high number of message copies and collisions within the vehicular network, which is sometimes called as *broadcast storm*.**

Our proposed technique, namely *Selective Reliable Broadcast* protocol (SRB), is intended to limit the number of packet transmissions, by means of *opportunistically* selecting neighboring nodes, acting as relay nodes. The number of forwarder vehicles is strongly reduced, while network performance is preserved. Simulation results have shown the effectiveness of SRB as compared to traditional broadcast protocol.

***Index Terms*—Vehicular networks, cluster-based protocol, broadcast storm problem.**

I. Introduction

Vehicular Ad hoc NETworks (VANETs) are emerging as the preferred network design for Intelligent Transportation Systems, providing communications among nearby vehicles in the support of Internet access, as well as several safety applications. VANETs rise from traditional Mobile Ad-hoc NETworks (MANETs), while showing many different aspects. They consist of mostly highly mobile nodes moving in the same or opposite directions (*i.e.*, vehicles), forming clusters [1]. Inter-vehicle communications are expected to significantly improve transportation safety and mobility on the road.

Most applications targeting VANETs rely heavily on broadcast transmission, both to discover nearby vehicles, and to disseminate traffic-related information to all reachable vehicles within a certain geographical area, rather than only to routing-selected hosts, like in MANETs. On the other side, broadcasting packets may lead to frequent contention and collisions due to redundant transmissions among neighboring vehicles, in dense network topologies. This problem is referred to as the *broadcast storm problem* [2], [3].

Although multiple solutions exist to alleviate the broadcast storm effect in the usual MANET environment, only a few solutions have been proposed addressing the VANET context [4], [5]. Most of recent research works have focused on analyzing VANETs as *well-connected* networks, providing high vehicular traffic density. In contrast, in low vehicular traffic density environment, vehicular connectivity results intermittent, poor, and short-lived [3]. In this context, the design of reliable and efficient routing protocols, supporting highly diverse and intermittently connected network topologies, is still a challenge.

In this paper, we propose an effective broadcast method for diffusing safety messages in VANETs, which relies on the opportunistic cluster selection in order to reduce the broadcast storm effect. Our technique is called *Selective Reliable Broadcast* (SRB) protocol. As already discussed in [6], the main aim of SRB is to reduce the number of broadcast messages. SRB selects only one vehicle within a cluster—namely, a *cluster-head*—which efficiently rebroadcasts emergency and control messages.

This paper is organized as follows. In Section II, we extend the previous work in [6] and describe the cluster detection mechanism in more detail, by means of the algorithm implemented in SRB. Moreover, in order to enforce the benefit of SRB, in Section III we stress the simulation results by a comparison with traditional broadcast protocol. We show that SRB provides an automatic cluster detection mechanism, while keeping low the number of forwarder vehicles. Finally, conclusions are drawn in Section IV.

II. Selective Reliable Broadcast

The aim of SRB is twofold: (*i*) to avoid rebroadcast messages (*i.e.*, a limitation of broadcast storm problem), and (*ii*) to detect clusters in a fast and automatic way. The proposed approach considers the message rebroadcast process within a VANET by selecting a limited number of vehicles, acting as forwarders. Far from traditional broadcast routing, SRB detects clusters of vehicles in a fast and efficient way, and choosess one Cluster-Head (CH) vehicle for each cluster detected. The CH is then selected as the next message forwarder.

We assume a hybrid traffic scenario, consisting of both high and low speed vehicles, as well as high and low vehicle density areas. This scenario well depicts a real vehicular environment,

i.e. an urban area with congested entries. To avoid sudden and emergency braking, information about congested areas should reach high speed approaching vehicles in a timely fashion. We consider an aggregated vehicles group as a Zone-of-Relevance (ZOR) [1], depicted by the following features *i.e.*, (*i*) high vehicular density, and (*ii*) low vehicle speed. We will show how SRB is able to *efficiently* discover the ZOR (*i.e.*, with low overhead and delay).

SRB leverages on two main assumptions, *i.e.* (*i*) the vehicular area is partitioned in adjacent sectors, and (*ii*) all vehicles equipped with GPS are able to estimate their own position. SRB considers a contention resolution procedure necessary to detect the ZOR and nearby clusters, and then elects relay nodes, each per single cluster. The contention procedure and cluster detection mechanism are detailed as follows:

- **RTB transmission**: A source vehicle transmits a Request-to-Broadcast (RTB) control message to all neighboring vehicles in the transmission range. The RTB is a MAC-broadcast packet that contains the geographical position of the transmitter node. In the first hop, the message propagation direction is omnidirectional, while it changes for the next hops;
- **Waiting time calculation**: Upon receiving an RTB, vehicles compute their distance from the source vehicle (*i.e.*, d [m]). The distance information is exploited in the calculation of the *waiting time i.e.*, t_w [s], as follows:

$$t_w = \left[\frac{r_{tx} - d}{r_{tx}} \cdot (CW_{max} - CW_{min}) + CW_{\min} \right] \cdot t_{slot}, \quad (1)$$

  where r_{tx} [m] is the transmission range, and $CW_{max,min}$ are the maximum and minimum contention window sizes, respectively. By using (1) vehicles in the further regions always transmit before the others. According to the CSMA/CA policy of IEEE 802.11, the backoff time is decremented by 1 at each idle slot, while the decrease is stopped when the medium is busy;
- **CTB transmission**: Whenever the *waiting time* associated to a vehicle countdowns to zero, the vehicle sends back to the source a Clear-to-Broadcast (CTB) packet, containing the vehicle ID and its distance from the source. After receiving a valid CTB packet, vehicles exit the contention phase; in case of collisions, vehicles remain in the contention phase and resume the backoff process;
- **Cluster detection**: The source vehicle receives information on the ID and the distance from its nearby vehicles. By measuring the Direction of Arrival of the CTB messages, the source vehicle is able to calculate all the mutual inter-vehicle distances among its nearby vehicles. If the distance between each couple of nearby vehicles is lower than a threshold value (*i.e.*, D_{min}), the two vehicles will be considered belonging to the same cluster. The choice of D_{min} influences the number of clusters identified: the higher the distance threshold, the higher the number of vehicles in each cluster. When $0 \leftarrow D_{min}$, each vehicle identifies a 1-size cluster;
- **Cluster-head election**: After detecting multiple clusters, the source vehicle elects the furthest vehicle inside each cluster as the Cluster-Head, and transmits a data message only to such vehicle. We assume that the data message has a length of 1526 byte. Upon receiving the data message, each CH will become the message source for the next contention phase, and the SRB algorithm is repeated for the next hops.

[1]The term ZOR is used with the meaning of a congested traffic area.

III. Simulation Results

In this section, we analyze the performance of the proposed technique in an urban scenario. We generate a 4 kilometers square grid with one lane per direction, through the VanetMobiSim software [7]. We assume there are some ZORs, as previously defined, in unknown areas. Packets are generated with a constant generation rate (*i.e.*, λ [pck/s]), and are transmitted according to a fixed data rate (*i.e.*, R [Mb/s]), within a fixed transmission range (*i.e.*, r_{tx} [m]). All vehicles are equipped with a GPS receiver and radio interfaces, compliant with the IEEE 802.11b standard, with the following characteristics: $r_{tx} = 300$ m and $R = 6$ Mbps.

In order to assess the effectiveness of the proposed SRB protocol, we compare network performance with traditional broadcast approach, since SRB rises from this protocol. Performance have been evaluated in terms of average (*i*) throughput, and (*ii*) message propagation, by means of numerical simulations carried out with the ns-2.34 simulator [8]. In this scenario, we assume 150 vehicles are moving at constant speeds, and forming clusters only for a limited—short-life—time interval. We also consider $D_{min} = 150$ m that is a good trade-off with the transmission range (*i.e.*, $D_{min} = r_{tx}/2$).

Fig. 1 depicts the *average throughput* [bit/s] experienced by vehicles communicating with each others, in the case of SRB and traditional broadcast. During the simulation time, the vehicle cluster aggregation occurs in a random fashion, due to the non-homogeneous nature of the urban scenario (*i.e.*, the presence of junctions and traffic lights can reduce cluster formation). We observe a variable behavior of throughput experienced in SRB technique, as shown in Fig. 1 (*a*): in the first part of the simulation (*i.e.*, for $t < 50$ s), the throughput shows high values and reaches 30 kbps, while in the second part (*i.e.*, for $t \geq 50$ s) low values of throughput occur. This is justified by an increase of data exchange for $t < 50$ s, when the cluster detection occurs; while for $t \geq 50$ s vehicle aggregation is reduced and traffic flow becomes uncongested.

By comparing results in Fig. 1 (*a*) and (*b*), we notice that SRB reaches peaks of 30 kbps, while for vehicles broadcasting packets the performance is limited to 5 kbps that could appear as a quite counterintuitive result. Basically, for a simple broadcast approach the vehicles forward messages to all their neighbors, causing multiple copies of the same message, as well as higher collision probability. On the other side, SRB allows only a limited number of vehicles to retransmit packets, opportunistically selected, thus reducing the collision probability, as well as the number of message replica. In the

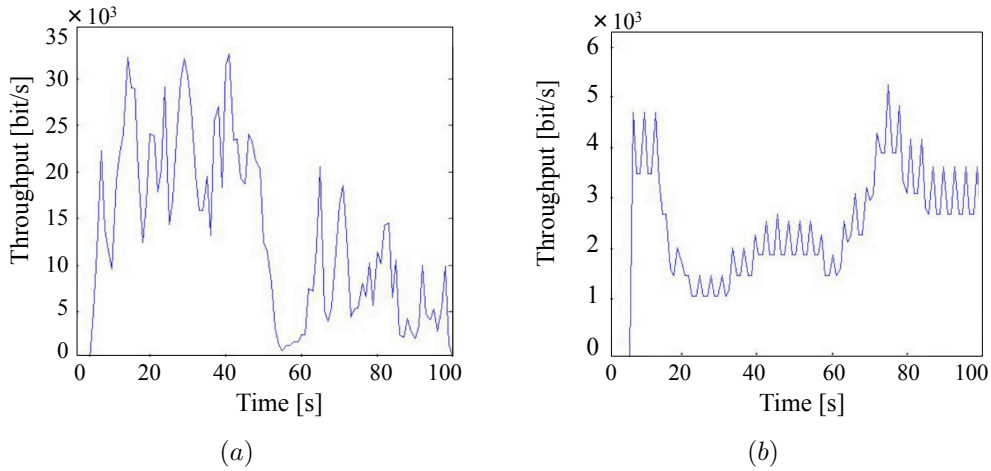

Fig. 1. Average throughput in urban scenario for (*a*) SRB technique and (*b*) broadcast approach, vs. simulation time.

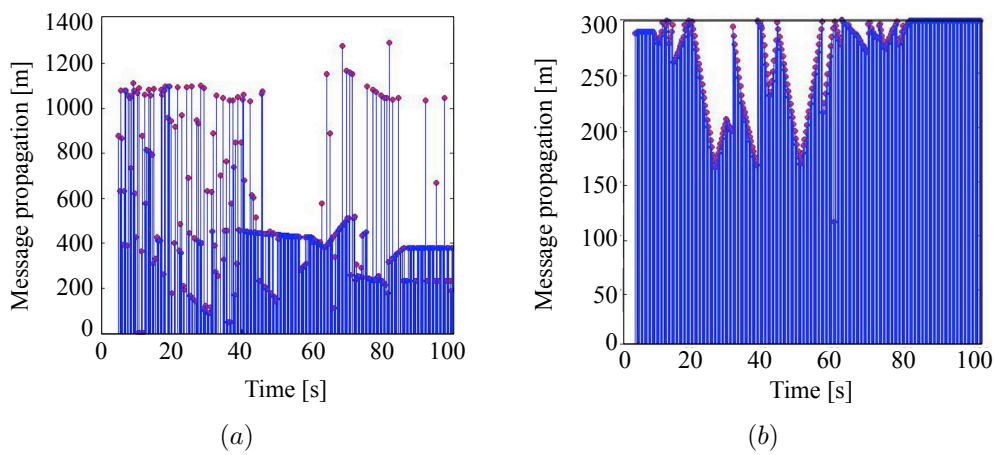

Fig. 2. Average message propagation in urban scenario for (*a*) SRB technique and (*b*) broadcast approach, vs. simulation time.

broadcast case, the low value of average throughput is due only to the effective transmitted messages, without multiple copies and the collided ones.

In Fig. 2 (*a*) and (*b*) is depicted the *average message propagation* [m], for SRB and broadcast protocols, respectively. Data messages for SRB propagate in the network and reach on average long distances (*i.e.*, up to 1.3 km far from the source); the vehicular environment is then almost fully "covered". It is also important to notice that performance trend reaches high values since a few seconds from the beginning of the simulation. These results suggest that the vehicular connectivity via SRB is largely guaranteed in the network. On the other hand, in Fig. 2 (*b*) for traditional broadcast the message propagation shows low values (*i.e.*, < 300 m corresponding to the maximum one-hop size). Again, this is due mainly to the number of collisions and the packet drop probability; for each hop, packets are transmitted by a source to all the neighbors, resulting as a *broadcast storm*.

IV. Conclusions

In this paper we have investigated recent efforts for mitigating the *broadcast storm problem* in VANETs. SRB is a cluster-based routing protocol, and allows vehicles to selectively transmit messages within their own transmission range, resulting in a reduction of network overload, and message duplication. We have shown that SRB outperforms the traditional broadcast protocol, and is particularly effective for safety applications.

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