Poster: Towards 2-Hop Neighbor Management for Heterogeneous Vehicular Networks

Ion Turcanu*, Minsuk Kim* and Florian Klingler†
*SnT, University of Luxembourg, Luxembourg
†Dept. of Computer Science, Paderborn University, Germany
ion.turcanu@uni.lu, minsuk.kim.001@student.uni.lu, mail@fklingler.net

***Abstract*—Message dissemination protocols for vehicular networks often build upon information maintained in neighbor tables. Due to high mobility and scarce channel capacity available in such networks, algorithms for maintaining neighbor tables must carefully select which information is transmitted at which time. Recent approaches rely on probabilistic data structures (e.g., Bloom filter) for transmitting such neighbor information in order to reduce channel load, yet they still suffer from scarce channel capacities. In this paper, we propose to use multiple communication technologies (heterogeneous networking) for maintaining neighbor tables by building upon recent 2-hop neighbor management strategies. Promising results show an increase of up to 19 % of covered neighbors in comparison to a Baseline approach that only uses one communication technology.**

I. Introduction

Periodic dissemination of 1-hop broadcast messages in Vehicular Ad-Hoc Networks (VANETs), named *beaconing*, is used for cooperative awareness and road traffic safety applications. These control messages, standardized as Cooperative Awareness Messages (CAMs) (see ETSI EN 302 637-2), include the vehicle's status information, e.g., current position, speed, heading, unique identification. This information is maintained by every receiving vehicle in a local neighbor table (see ETSI EN 302 895) and can be used by safety applications or routing protocols, such as GeoNetworking (see ETSI EN 302 636-4-1).

Recently, this approach has been extended for maintaining 2-hop neighbor information [1] for better network topology management in highly dynamic vehicular networks. However, exchanging 2-hop neighbor information introduces additional load on the already scarce channel resources. Klingler et al. [1] propose to cope with this issue by taking advantage of probabilistic data structures. Other solutions focus on dynamic beaconing approaches, where the beacon interval is adjusted based on the channel load [2], number of neighbors [3], or targets specific applications [4] with the objective to avoid overloading the wireless channel.

Yet, efficiency in scenarios with high node density is still a problem. In this context, heterogeneous networking approaches have been proposed to help better deal with scarce channel resources of particular communication technologies [5]–[7]. However, existing solutions either rely on centralized interface selection mechanisms [5], [7] or focus on 1-hop message delivery performance [6] only.

In this paper we combine both directions: (i) using 2-hop neighbor information, and (ii) exploiting heterogeneous vehicular networking. In particular, we extend the recent *Bloom hopping* [1] neighbor table management and multi-hop message forwarding approach to support heterogeneous networking capabilities in order to improve multi-hop broadcast communication performance.

II. Heterogeneous 2-Hop Neighbor Management

We assume vehicles periodically exchange beacon messages to maintain 2-hop neighbor information, as described in [1]. In particular, each vehicle includes in every beacon a Bloom filter containing the current list of 1-hop neighbor IDs. Bloom filters have the advantage of being space efficient, which decreases the load on the communication channel with respect to simple lists, but introduce a non-zero probability of having false positives. In this paper, we assume ideal Bloom filters (i.e., the probability of false positives is 0) in order to evaluate the performance of the heterogeneous networking approach. For simplicity reasons, we also assume all vehicles use the same fixed beacon interval BI. On the receiving side, each vehicle updates the corresponding records in the local neighbor table every time a new beacon is received. The information in the neighbor table becomes obsolete and it is deleted if three consecutive beacons are not received, either because of congested channel or the sending vehicle is not in the communication range anymore.

In this paper, we assume vehicles are equipped with multiple wireless communication technologies (e.g., IEEE 802.11p/bd, C-V2X/5G-NR, VLC). Let N be the number of available technologies. Then every vehicle is equipped with N wireless network interfaces. We propose to extend the neighbor table management process described above by allowing vehicles to exchange beacon messages across all N interfaces and maintain a dedicated neighbor table for every communication technology. Since every technology can have particular characteristics (e.g., communication range, frequency), the content of these neighbor tables can be different.

The multi-hop message forwarding approach described in [1] exploits the 2-hop neighbor table information to support efficient broadcast-based data dissemination in VANETs. In particular, every sender (generator or forwarder) of a data message (e.g., an event-based warning message) identifies a subset of its 1-hop neighbors as the next forwarders for this message, which is then included in the data message itself.

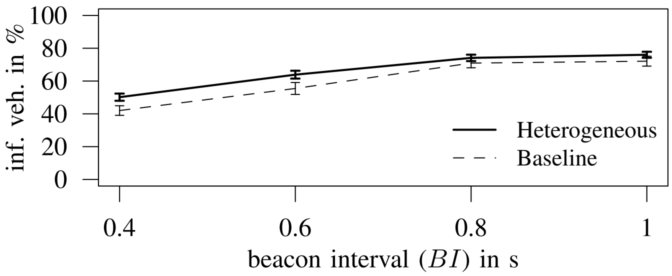

Figure 1. Forwarding algorithm performance for different beacon intervals.

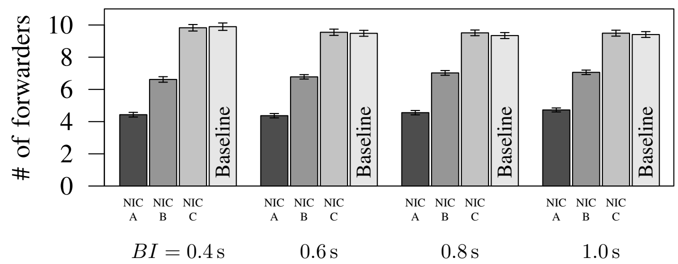

Figure 2. Number of forwarders for different NICs and beacon intervals.

The selection process is based on a greedy iterative process that selects the 1-hop neighbor u that covers the most 2-hop (uncovered) neighbors up until all 2-hop neighbors are covered.

In this paper we propose a simple approach that extends the forwarder selection process described in [1] to heterogeneous networks. A sender selects the next forwarders by applying the forwarding algorithm on each neighbor table (for every communication technology) consecutively, starting with the one having the smallest number of 1-hop neighbors. For each communication technology available in the set of selected forwarders, a data message is broadcast including the information which forwarder should rebroadcast the message. Whenever a node receives a data message where its ID is included in the forwarder list, the node rebroadcasts the message with a random delay to avoid synchronized collisions.

III. Performance Evaluation

To validate the proposed solution, we implemented both the heterogeneous 2-hop neighbor management and forwarding algorithm in a realistic simulation framework in Veins 5.0. We simulate a 2.9 km x 2.9 km Manhattan Grid scenario without obstacles and with an average traffic density of 80 veh/km^2. To avoid border effects, we only collect statistics in a 2.2 km x 2.2 km region inside the simulated scenario. Every vehicle is equipped with three IEEE 802.11p Network Interface Cards (NICs) – A, B, and C – each configured on a different non-overlapping 10 MHz channel in the 5.9 GHz frequency band and with a different transmission power (to emulate different communication characteristics), as follows: 5.87 GHz and 5 mW for NIC A, 5.89 GHz and 10 mW for NIC B, 5.91 GHz and 20 mW for NIC C. This configuration yields a communication range (the $99^{\text{th}}\%$ of the measured distance between any two vehicles exchanging beacons) of around 270 m (NIC A), 378 m (NIC B), and 529 m (NIC C).

For evaluation, we periodically (every 2 s) randomly select five vehicles within a 500 m radius in the center of the simulated scenario to generate a data message. For simplicity we focus here on the case where the message is forwarded only up to 2-hop neighbors. To transmit messages to a larger area, a forwarder could reapply the proposed algorithm. In Figure 1 we illustrate the average percentage of vehicles that receive the warning message for different beacon intervals. Here, we compare the proposed heterogeneous approach to a baseline that uses only one communication technology, namely the one with the largest communication distance – NIC C. The results show that our heterogeneous approach clearly outperforms the baseline improving it up to 19 %. In Figure 2 we show the mean number of selected forwarders across different communication technologies and the Baseline approach. Obviously, more forwarders are selected on the interfaces that can reach a larger number of neighbors. However, the most interesting result is that the number of forwarders on NIC C in case of both, our heterogeneous approach and the baseline, are very similar. This means that our heterogeneous approach is able to reach more neighbors at no additional cost at NIC C, which demonstrates the advantage of using multiple communication technologies in a vehicular network.

IV. Conclusion

In this paper we take a first step towards neighbor management and multi-hop message forwarding based on heterogeneous communication in vehicular networks. Particularly we propose a heterogeneous message forwarding algorithm based on novel 2-hop neighbor table management strategies. We build upon the Bloom Hopping protocol by adding capabilities for using multiple communication technologies to improve the coverage of all neighbors within 2-hop range. Promising results of our protocol show that we are able to increase the covered neighbors by up to 19 % in comparison to a baseline approach that uses only a single communication technology.

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