Bad Neighbors? On the Impact of IEEE 802.11p and Cellular 5G on Vehicular Neighbor Sets

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***Abstract*—In vehicular networks, information about the surroundings is of crucial importance. There are various applications that rely on information about a vehicle's neighboring vehicles, such as autonomous and teleoperated driving, platooning and message forwarding being some of them. While maintaining an overview of vehicles in direct communication range via beaconing is a well-explored concept, recent works have shown that collecting the neighbor information of direct neighbors, which are the neighbor's neighbors, is beneficial for certain applications. This data can be aggregated to the so-called two-hop neighbor set. Creating an accurate two-hop neighbor set is, however, a difficult task, as information is quickly outdated due to the mobility of vehicles and delays of data transmission. While previous work has used mainly ad-hoc communication, this work introduces a central vision utilizing 5G cellular communication to improve the freshness of neighbor data. We conduct a first simulation study to compare the performance of our centralized approach to a purely ad-hoc approach and present the results in this poster paper. We conclude with an outlook to future research directions. In future work, a deeper investigation of potential optimizations and challenges will be conducted.**

I. Introduction and Related Work

In vehicular networks, neighbor information is of crucial importance for a broad range of applications. To notify nearby vehicles of the own presence, position and intentions, the state-of-the-art approach is to send so-called beacons periodically [1]. The information from received beacons are then saved in a *neighbor table*. Extending the range of gathered information to not only include direct (one-hop) neighbors, but also the direct neighbors of the direct neighbors (the two-hop neighbors), has proven beneficial [2]. This approach does, however, come at the cost of large amounts of data that have to be transferred, as the list of one-hop neighbors has to be included in beacons sent. Larger beacon sizes prolong the time a vehicle blocks the wireless channel, leading to an increased risk of frame collisions and therefor information loss, resulting in incomplete or outdated neighbor sets.

Previous work has shown that probabilistic data structures can be used to decrease the beacon size [3]. However, reducing the beacon size does not solve the issue of packet loss caused by, e.g., shadowing or hidden terminal problems. To overcome this issue and make the information exchange more reliable, heterogeneous communication technologies can be used: Instead of relying on a single technology, vehicles are equipped with multiple communication technologies, such as cellular 5G and IEEE 802.11p [4], [5]. Luo et al. [6] introduced the term *5G-VANET* that describes the heterogeneous nature of combining ad-hoc and cellular networking. Turcanu et al. [4] simulated the usage of heterogeneous ad-hoc communication technologies and showed that the neighbor set coverage and accuracy benefits from such an approach. Shah et al. [7] described how IEEE 802.11p and 5G cellular can both be utilized for V2X communication, with 5G supplementing the already widespread IEEE 802.11p.

In this paper, we investigate the potential of 5G-VANETs to improve the two-hop neighbor set, utilizing both ad-hoc and cellular communication.

II. Our Approach

Vehicles broadcast beacons containing their position and their neighbor table (empty in the beginning) via IEEE 802.11p (ad hoc) to their direct neighbors periodically. Whenever any vehicle receives a beacon, they add it to their own neighbor table. Furthermore, vehicles send beacons containing their identifier and position to a central server periodically using 5G. The server uses the beacons to calculate the theoretical one-hop and two-hop neighbors of each vehicle, based on a unit disc calculation approximating the communication distance of the IEEE 802.11p radios. It sends this data back to the corresponding vehicle via 5G. We compare the one-hop and two-hop neighbor sets calculated by the server and the sets generated via the ad-hoc approach to an oracle that serves as ground truth. The oracle calculates the ideal one- and two-hop neighbor sets based on a unit disc approach and the actual, non-delayed position of each vehicle. In order to quantify the accuracy of the neighbor sets, we calculate the missing nodes and outdated nodes: Missing nodes are present in the oracle, but not in the measured sets. Outdated nodes are present in the measured sets, but not in the oracle, which means that the vehicle has moved out of the communication range in the oracle, but is still present in the measured neighbor table.

We compare two approaches: The *naïve* approach sends the neighbor data as a plain table, which leads to variable beacon sizes, whereas the *fixed-size* approach uses a fixed beacon size, mimicking an idealized probabilistic data structure. To the best of our knowledge, this comparison has not yet been done before.

III. Evaluation

We conduct a simulation study using OMNeT++, Veins_-INET, SUMO and Simu5G.

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A. Simulation Setup

We use a freeway scenario of 5 km length and bidirectional traffic on four lanes per direction. The average traffic density is 146 vehicles per km. We conduct 100 repetitions of our simulations for statistical confidence. The vehicle's IEEE 802.11p radios use a transmission power of 20mW, sending on a 5.9GHz center frequency using a bandwidth of 10MHz. For the 5G communication, one base station is placed in the center of the freeway, using a transmission power of 40dBm. The 5G radios use a transmission power of 26dBm. For the remaining parameters, Simu5G's standard values are used.

We assume that every entry in a neighbor table occupies the size of a MAC address (6 Bytes). The IEEE 802.11p header size is 64 Bytes. Therefore, every packet sent using dynamically sized beacons has a length of 64 Bytes + 6 Bytes times the number of one-hop neighbors sent. For fixed-size beacons we assume 244 Bytes (64 Bytes for the header, 180 Bytes for a large Bloom Filter [3]). Beacons that are addressed to the server via 5G only contain the header as well as the sender's MAC address and position, which amounts to 64 + 6 + 24 (three doubles) Bytes. If no beacon has been received by a neighbor for more than one second, the corresponding entry is removed from the neighbor table. A vehicle sends a beacon via both IEEE 802.11p and 5G every 0.2s. A unit disc radius of 334 m was empirically determined and is used for the oracle calculations.

B. Evaluation

Figures 1 and 2 show the results of the fixed-size approach: 26% (one-hop) and 31% (two-hop) of the neighbors calculated by the oracle are missing for the IEEE 802.11p approach. 0.4% (one-hop) and 27% (two-hop) of the neighbors are outdated. The 5G approach performed substantially better, showing only 1% (one-hop) and 2% (two-hop) missing neighbors, with 0.5% (one-hop) and 1.6% (two-hop) of the neighbors being outdated. The naïve (dynamic beacon size) approach resulted in substantially higher missing and outdated ratios, with 36% (one-hop) and 43% (two-hop) missing and as 0.25% (one-hop) and 37% (two-hop) outdated neighbors (data not shown). The ratio of outdated one-hop neighbors is slightly lower for the naïve approach, which is likely to be the result of the higher information loss, which has the side effect of delivering less data to be outdated. The performance of the 5G approach is identical in both the naïve and the fixed-size approach. The better performance of the fixed-size approach is explained by the lower channel load, resulting in fewer frame collisions (ca. 31% less for the fixed-size approach, data not shown), less packet loss and therefore more information being correctly received by the vehicles [3]. The high number of outdated two-hop neighbors is the result of missing one-hop neighbors being considered as two-hop neighbors, as their identifiers are present in the two-hop neighbor set. Our results show that 5G can improve the neighbor sets substantially.

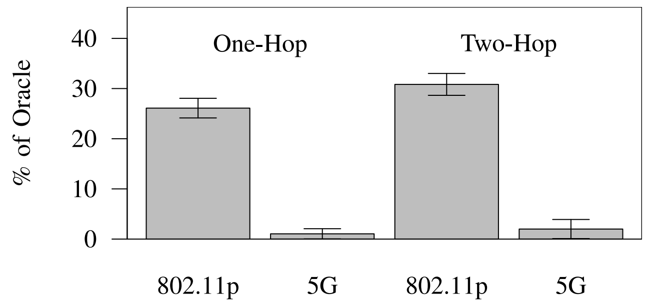

Figure 1. Missing nodes percentage, compared to oracle. Arrows show the 95% confidence interval.

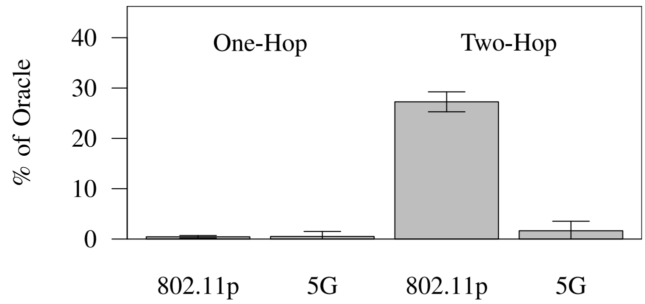

Figure 2. Outdated nodes percentage, compared to oracle. Arrows show the 95% confidence interval.

IV. Conclusion and Future Work

We investigated the neighbor table performance of pure ad-hoc communication in comparison to a centralized and 5G-based neighbor management approach. First results of our simulation study indicate that supplementing data gathered through classic ad-hoc beaconing by data calculated by a central entity might be beneficial. In future work, we will investigate possibilities to combine the separate neighbor sets and get the best and most recent information out of them.

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