Research Statement: Heterogeneous Vehicular Networks

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***Abstract*—Car-to-car and car-to-infrastructure communication enables a lot of different application scenarios. The most popular way of using WLAN communication between cars might not be good enough for every use case. If as an alternative cellular networks are used, capacity problems arise. This is why so called heterogeneous vehicular networks attract more and more attention. Cars that make use of such networks are usually equipped with WLAN and cellular devices. Such a combination is able to overcome shortcomings of one technology by using the other one. Still, the tools used to evaluate such algorithms are not sufficient. I want to fix this by adding heterogeneous vehicular networking functionality to existing tools. Additionally, I want to investigate how multiple heterogeneous vehicular networking algorithms work when used together. A possible outcome could be more general concepts, with a focus on clustering, to enable multiple algorithms running beside each other.**

I. Introduction

In the area of Inter-Vehicle Communication (IVC) application scenarios can be divided into three categories: Safety, Information, and Entertainment.

- **Safety** covers applications related to driver safety. One example are collision avoidance applications which do not require Line of Sight (LOS) to work. Such applications usually require high reliability and small delays.
- The second category are **efficiency** applications. These applications inform drivers about traffic related news and give them more opportunities to plan their journey. The requirements regarding reliability and delay are not as strict as for *safety* applications.
- The final category of applications can be classified as **entertainment**. Example scenarios covered by this category are streaming of movies or storage of data in parked cars. Generally this is a broad field that covers everything not related to *safety* or *efficiency*. Therefore, the requirements mostly depend on the concrete scenario.

All these application scenarios are mostly based on forming Vehicular ad-hoc networks (VANETs). Communication happens largely via WLAN based technologies like IEEE 802.11p and rarely by using cellular technologies like Long Term Evolution (LTE). Both of these technologies have their advantages and downsides in terms of e.g. delay, reliability.

- Cellular technologies are not able to support a high frequency of messages. Even if a lot of messages for safety applications are supported that might lead to a significantly degraded service quality for non-vehicular users.
- WLAN technologies might not be able to cover dense urban areas and the initial coverage will be really low compared to cellular.

To overcome these shortcomings both technologies can be combined in *Heterogeneous Vehicular Networks*. A car that takes part in such a network is equipped with a WLAN and a cellular communication device. In addition, most of the heterogeneous applications need a way to cluster vehicles. The details how clustering happens is different in [1]–[7].

My research will focus on the question how multiple heterogeneous vehicular applications running in parallel will influence their performance. On the one hand I want to investigate how using different specialized clustering algorithms in parallel affects the performance of such applications. In such a case the message overhead will probably increase and solutions are needed. On the other hand I want to investigate how vehicles act in such heterogeneous vehicular networks as a data and information source for the future. This can be done by combining different application scenarios in a single network with multiple algorithms running in parallel. Until now, most algorithms have been evaluated in isolated scenarios. To my knowledge at best they were using just average Internet traffic and not other heterogeneous vehicular algorithms.

My proposed approach is to initially build tools that allow a complete simulation of heterogeneous vehicular networks. This simulator should be able to run multiple applications on top of a heterogeneous network stack. With these tools I am also able to simulate different clustering algorithms and evaluate their feasibility if multiple applications run on top of them. A possible outcome would be a more general concept how to design such algorithms and bring them closer to real world usage.

II. State of the Art

There are a lot of publications trying to combine WLAN and cellular communication for IVC. One example in this area is MobTorrent [1] which allows users to download data using vehicles as access points. The cellular connection here is mainly used to coordinate downloads via WiFi. In [2] a heterogeneous approach is taken to build a traffic information system (TIS). This TIS builds a shared database of travel times along road segments which allows other users to plan their journey. Neighboring cars are connected via direct communication links to achieve a better performance of the algorithm. Others focus on providing a link to the Internet for cars without a cellular connection [3]–[5]. In [3] an architecture for a heterogeneous network and how to build the clusters is proposed. [4] extends this concept even further and optimizes the number of cellular hand-overs. The clustering parameters in [3] and [4] are the direction of movement, the cellular signal strength and the WLAN transmission range. A different approach to clustering in such networks is taken by [5] which uses game theory to build the best possible clusters. Additionally the proposed concept is evaluated in simulation scenarios. Beside [2] (*efficiency*), these earlier works can be categorized as *entertainment*. Two more recent algorithms are by Tung et al. [6] and by Rémy et al. [7] and can be placed in the categories of *safety* and *efficiency*. Both use WLAN technologies (IEEE 802.11p) to let vehicles communicate in close range and form clusters. A dedicated vehicle of such a cluster is then the cluster head and communicates with other clusters via LTE. While [6] focuses on collision avoidance, [7] is about collecting vehicle data at a central server and sharing them with other users.

What most of these works have in common is the usage of simulation for evaluation, only [1] uses experiments. In [8] it is proposed that every application related to *safety* and *efficiency* has a feedback loop between the network and the traffic simulator. But [2], [6], [7] lack such a feedback loop, while others like [5] do not specify the used simulation environment. Therefore, a simulator which provides such a loop is needed. A final interesting approach is taken by Katsaros et al. [9] who try to reduce load on the WLAN by using the cellular connection for a location service. The authors conclude that their algorithm significantly reduces load on the WLAN network but does not increase the load on the LTE network. What all these approaches have in common is that the only evaluate a single isolated scenario and do not take into account other heterogeneous applications that send messages.

III. Contributions

My research focuses on three steps: First I want to build a tool to evaluate heterogeneous vehicular networking algorithms. The second task, clustering related questions, and the third one about combining multiple applications, are closely related to each other.

- **Extend our feedback loop simulator to support simulation heterogeneous vehicular networks.** As there are various *safety* and *efficiency* applications that alter the traffic flow a feedback loop is in need. Without such a bidirectional connection between the network and the traffic simulator evaluation of such algorithms is not sufficient. Therefore we extended the Veins simulation environment to support LTE resulting in *VeinsLTE* [10]. It offers a feedback loop between the network and the mobility simulator as well as IEEE 802.11p and LTE support. During my research I want to extend this simulator. One possible idea would be to add *LTE Direct* as a possible replacement for WLAN.
- **How are clustering algorithms affecting different application scenarios?** Nearly every introduced algorithm uses clustering to distribute the load between the WLAN and the cellular network. If now multiple algorithms run in parallel cars need to take part in more than one cluster. This might lead to much more control message overhead. I want to explore the idea of a more general clustering scheme that abstract from the application and provides support for different applications.
- **Can cars be the central point for future IVC systems?** Vehicles that are equipped with multiple networking devices allow for a completely new look on the role of cars in Information and Communication Technology (ICT). As already stated there exist multiple algorithms for such heterogeneous vehicular networks and different use cases but they have never been combined into a single architecture. Together with Toyota[1] I am exploring ways how to make cars the main ICT resource and construct a network that supports multiple application scenarios.

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