Research Statement: Heterogeneous Communication in Cooperative Driving Applications

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***Abstract*—Cooperative driving applications like platooning and cooperative Intersection Collision Avoidance (ICA) conceived to tackle problems associated with modern traffic, like congested roads, traffic accidents, and inconvenience for the driver. Platooning in particular has been researched in detail, since it's introduction can already provide benefits at low market penetration rates. However, guaranteeing safety in platooning and other cooperative driving applications is still a challenge, due to the susceptibility of the communication methods to large vehicle densities and deliberate attacks on the network. During my PhD project I want to research how heterogeneous communication can be leveraged to tackle these problems. I will investigate how multiple communication protocols can be combined, such that cooperative driving applications can work more reliably and efficiently. In the end I aim to have explored different strategies using heterogeneous communication, and how these can be employed to develop protocols that enable reliable and safe cooperative driving.**

I. Introduction

A current trend in transportation is to fit vehicles with more and more sensors and computation logic. Using these devices, manufacturers hope to tackle the problems imposed by the large amount of traffic that can be observed on today's roads: Traffic jams which waste fuel and time, traffic accidents that cost lives on a daily basis, and the environmental impact of vehicles, most notably, their carbon footprint.

One Intelligent Transport System (ITS) application that aims to alleviate many of these issues is autonomous driving. This technology is set to allow vehicles to operate without human interaction and work more efficiently as its reactions to its environment are quicker and less error prone compared to a human driver.

Even with autonomous driving however, a vehicle can base its decisions solely on locally available information. Inter Vehicular Communication (IVC) can allow to go beyond this limitation by enabling *cooperative driving*, where vehicles communicate relevant information, e.g., speed changes, to other vehicles. Different applications have been conceived, which make use of this opportunity. One such application is *platooning*, the formation and control of a set of vehicles, which drive in close proximity and virtually behave like a single vehicle. This reduces the amount of road required for the vehicles, as well as their aerodynamic drag, leading to reduced fuel consumption [1]. In such a platoon, vehicles require accurate information of the other platoon members, to properly control their own velocities. Another area within which cooperative driving can lead to improvements is Intersection Collision Avoidance (ICA). Traditionally, traffic lights ore roundabouts are used to avoid accidents at intersections. These are, however, often inefficient, as vehicles might be required to slow down, or stop, unnecessarily. With a cooperative systems vehicles can communicate their approach ahead of an intersection and reach a consensus with other approaching vehicles on the crossing schedule at the intersection [2].

For the two mentioned applications, both safety and reliability is a huge concern. The promises can only be achieved if timely communication between vehicles can be guaranteed. To this end, current proposals mostly employ IEEE 802.11p, a standard of the WLAN protocol family adapted for the vehicular domain. It enables communication between vehicles up to several 100 m. The comparably large range comes with disadvantages however: The performance decreases in large vehicle densities as parallel transmissions cause packet collisions, and the network can easily be attacked, e.g., by jamming attacks [3].

To this end, *heterogeneous communication* might help improving reliability and safety. With heterogeneous communication, multiple different communication technologies are used in parallel. Technologies that might be used are IEEE 802.11p, 4G/5G (via an eNodeB as well as D2D), Vehicular Visibile Light Communication (VLC), and even mmWave reusing the vehicular radar as a communication device. These have different characteristics, e.g., the large interference domain of IEEE 802.11p is contrasted by the comparably small and directional area illuminated by a vehicle's lights used for VLC. These different properties can be leveraged to improve efficiency, reliability, and safety of communication, e.g., by using the most appropriate technology, or employing redundancy.

In my PhD studies I currently work on investigating this opportunity in detail. The novel approach requires new ideas on how communication algorithms and technologies can be integrated with each other to maximize the possible benefits.

II. State of the Art

There have been different studies conducted on heterogeneous communication in the context of cooperative driving. With the recent interest in VLC, in particular the combination of IEEE 802.11p with VLC has attracted attention. Ishihara et al.

[4] investigated how such a system can be used to alleviate the impact of a jamming attack on platooning performance. They formulated a protocol which can forward beacons via both IEEE 802.11p and a VLC link. In a simulation, the authors confirmed in a simulation that the amount of dropped packets during a jamming attack can be vastly reduced using the devised protocol. A more extensive protocol has been devised by Ucar et al. [5]. This uses VLC to reduce the influence of jamming attacks, but additionally secures the communication cryptographically, such that replay or forgery attacks can be prevented. In simulations, the authors demonstrate the system's resilience to different kinds of attacks.

In a different study, Segata et al. [6] investigated the performance of a heterogeneous beaconing protocol in a large scale simulation including up to 640 vehicles in a dense formation. Their transmits leader- and follower beacons with IEEE 802.11p and VLC respectively. They showed that even with pessimistic assumptions about the VLC link's performance, i.e., the Packet Delivery Ratio (PDR) of the leader beacon can be increased significantly.

While these publications researched platooning with heterogeneous communication based on IEEE 802.11p and VLC, Tung et al. [2] investigated a heterogeneous communication approach using Long Term Evolution (LTE) and IEEE 802.11p to support cooperative ICA. The authors combined a clustering approach to coordinate vehicles on each road approaching an intersection using short range communication, while providing an uplink for a single cluster member using LTE. This method aims to avoid connectivity issues that can be experienced when solely relying on IEEE 802.11p due to the limited range, as well as overloading the LTE cell, which is a risk when all vehicles use this technology. In a simulation the authors confirmed that using the heterogeneous protocol, both individual communication channels experience significantly less load compared to a single technology solution.

III. Open Tasks

During my PhD studies I aim to investigate in detail the integration of cooperative driving applications and heterogeneous communication. As a first step I plan to focus on integrating platooning with heterogeneous communication, as it is the most widely researched cooperative driving application. This integration is an emerging topic, however most existing work has been focused on security aspects, i.e., resilience to attacks, instead of improving reliability of regular operation. While the results of the existing work are promising, a detailed investigation of a tight integration between heterogeneous communication and platooning is, to the best of my knowledge, not yet conducted and required to understand important aspects of protocol design. Novel protocols have to be conceived in the context of heterogeneous communication, since the expanded design space allows for more flexible protocols.

Different technologies can be used in the context of heterogeneous communication. Ideally, the best results can likely be obtained when combining as many as of these technologies as possible. In order to allow for a systematic approach, however, I will limit this to only two technologies initially, namely IEEE 802.11p and VLC. These have seen the widest use in research so far, both for platooning in general, as well as in heterogeneous communication approaches. Additionally, they have very different propagation characteristics, in particular their interference domains. This makes them an ideal early candidate as it is possible to determine how complementing properties can be ideally combined.

Another different aspect in platooning is the controller, which computes the individual vehicle's acceleration. A multitude of controllers have been proposed, the most commonly one being that used by the PATH project [7]. As the controller has a large influence on the system performance. Alternatives might be viable, and even better suited for heterogeneous communication, e.g., due to different delays or irregular updates.

In order to investigate these aspects, I will employ detailed simulations. Tools for such simulations are publicly available, e.g., for platooning or VLC communication. However, some work is required to integrate them with each other, such that they can be used in conjunction.

In addition to the work on heterogeneous communication, I want to look into other emerging technologies that can be used for communication. In particular, radar-based communication is of interest here, since it might be possible by reusing components already present in vehicles.

References

[1] A. A. Alam, A. Gattami, and K. H. Johansson, "An Experimental Study on the Fuel Reduction Potential of Heavy Duty Vehicle Platooning," in *13th IEEE International Conference on Intelligent Transportation Systems (ITSC 2010)*, Madeira Island, Portugal: IEEE, 2010, pp. 306–311.

[2] L.-C. Tung, J. Mena, M. Gerla, and C. Sommer, "A Cluster Based Architecture for Intersection Collision Avoidance Using Heterogeneous Networks," in *12th IFIP/IEEE Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net 2013)*, Ajaccio, Corsica, France: IEEE, 2013.

[3] Ó. Puñal, C. Pereira, A. Aguiar, and J. Gross, "Experimental Characterization and Modeling of RF Jamming Attacks on VANETs," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 2, pp. 524–540, 2015.

[4] S. Ishihara, R. V. Rabsatt, and M. Gerla, "Improving Reliability of Platooning Control Messages Using Radio and Visible Light Hybrid Communication," in *7th IEEE Vehicular Networking Conference (VNC 2015)*, Kyoto, Japan: IEEE, 2015, pp. 96–103.

[5] S. Ucar, S. C. Ergen, and O. Ozkasap, "IEEE 802.11p and Visible Light Hybrid Communication based Secure Autonomous Platoon," *IEEE Transactions on Vehicular Technology*, 2018, to appear.

[6] M. Segata, R. Lo Cigno, H.-M. Tsai, and F. Dressler, "On Platooning Control using IEEE 802.11p in Conjunction with Visible Light Communications," in *12th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2016)*, Cortina d'Ampezzo, Italy: IEEE, 2016, pp. 124–127.

[7] R. Rajamani, H.-S. Tan, B. K. Law, and W.-B. Zhang, "Demonstration of Integrated Longitudinal and Lateral Control for the Operation of Automated Vehicles in Platoons," *IEEE Transactions on Control Systems Technology*, vol. 8, no. 4, pp. 695–708, 2000.