Report from Dagstuhl Seminar 21262

Inter-Vehicular Communication – From Edge Support to Vulnerable Road Users

Edited by

Ana Aguiar[1], Onur Altintas[2], Falko Dressler[3], and Gunnar Karlsson[4]

1 **Universidade do Porto, PT,** anaa@fe.up.pt
2 **Toyota Motors North America – Mountain View, US,** onur@us.toyota-itc.com
3 **TU Berlin, DE,** dressler@ccs-labs.org
4 **KTH Royal Institute of Technology – Stockholm, SE,** gk@kth.se

Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 21262 "Inter-Vehicular Communication – From Edge Support to Vulnerable Road Users". Looking back at the last decade, one can observe enormous progress in the domain of vehicular networking. In this growing community, many ongoing activities focus on the design of communication protocols to support safety applications, intelligent navigation, and many others. We shifted the focus from basic networking principles to open challenges in edge computing support and, as a novel aspect, on how to integrate so called vulnerable road users (VRU) into the picture.

Seminar June 28, 2021 – http://www.dagstuhl.de/21262
2012 ACM Subject Classification Networks → Network dynamics; Networks → Cyber-physical networks; Networks → Network reliability
Keywords and phrases vehicular networks, vulnerable road users, edge computing, intelligent transportation systems
Digital Object Identifier 10.4230/DagRep.11.5.89

1 Executive Summary

Falko Dressler (TU Berlin, DE)
Ana Aguiar (Universidade do Porto, PT)
Onur Altintas (Toyota Motors North America – Mountain View, US)
Gunnar Karlsson (KTH Royal Institute of Technology – Stockholm, SE)

Looking back at the last decade, one can observe enormous progress in the domain of vehicular networking. In this growing community, many ongoing activities focus on the design of communication protocols to support safety applications, intelligent navigation, cooperative driving and others. Using the terms Vehicular Ad-hoc Networks (VANETs), Inter-Vehicle Communication (IVC), Car-2-X (C2X), or Vehicle-2-X (V2X), many applications – as interesting as challenging – have been envisioned and (at least) partially realized. Very large projects have been initiated to validate the theoretic work in field tests and protocols are being standardized. With the increasing interest from industry, security and privacy have also become crucial aspects in the stage of protocol design in order to support a smooth and carefully planned roll-out. We are now entering an era that might change the game in road traffic management. Many car makers already supply their recent brands with cellular and WiFi modems, some also adding vehicular WLAN (DSRC, ITS-G5) and/or C-V2X technologies, which focus on V2V and V2I communication.

The management and control of network connections among vehicles and between vehicles and an existing network infrastructure is currently one of the most challenging and active research fields in the networking domain. There is a long list of desirable applications that can be grouped into four IVC categories:

1. e-Safety applications that try to make driving safer, e.g., road hazard warning, collision warning;
2. traffic efficiency applications aiming at more efficient and thus greener traffic, e.g., detection of traffic jams, traffic distribution;
3. manufacturer oriented applications, e.g., automatic software updates; and
4. convenience applications, e.g., automatic map updates.

We initiated the "Inter-Vehicular Communication" Dagstuhl Series back in 2010, when a first Dagstuhl Seminar was organized on this topic. The motivation was to bring together experts in this field to investigate the state of the art and to highlight where sufficient solutions already existed. The main outcome of this very inspiring seminar series was that there are indeed areas within this research field where scientific findings are being consolidated and adopted by industry. This was the consensus of quite intriguing discussions among participants from both industry and academia. Yet, even more aspects have been identified where substantial research is still needed.

Some of the findings of the first three seminars in this series have been published not only in the related Dagstuhl reports but also in widely visible magazine articles:

1. Falko Dressler, Frank Kargl, Jörg Ott, Ozan K. Tonguz and Lars Wischhof, "Research Challenges in Inter-Vehicular Communication – Lessons of the 2010 Dagstuhl Seminar," IEEE Communications Magazine, vol. 49 (5), pp. 158-164, May 2011.
2. Falko Dressler, Hannes Hartenstein, Onur Altintas and Ozan K. Tonguz, "Inter-Vehicle Communication – Quo Vadis," IEEE Communications Magazine, vol. 52 (6), pp. 170-177, June 2014.
3. Onur Altintas, Suman Banerjee, Falko Dressler and Geert Heijenk, "Executive Summary – Inter-Vehicular Communication Towards Cooperative Driving," Proceedings of Dagstuhl Seminar 18202 on Inter-Vehicular Communication – Towards Cooperative Driving, Schloss Dagstuhl, Germany, May 2018, pp. 31–59.

Seminars in this series focused on general vehicular communication technologies, security and safety impact, cooperative driving concepts and its implications on communication protocol design, and many more.

We now shifted the focus of this seminar from basic networking principles to open challenges in edge computing support and, as a novel aspect, on how to integrate so called vulnerable road users (VRU) into the picture. Edge computing is currently becoming one of the core building blocks of cellular networks, including 5G, and it is necessary to study how to integrate ICT components of moving systems. The trade-offs of computation distribution, system aspects, and the impact on end-to-end latency are still unanswered. Also, vehicular networking and cooperative driving focuses almost exclusively on cars but leaves out communication and coordination with, for example, pedestrians and bicyclists. For example, many of the existing communication solutions for this scenario were designed without having battery constraints in mind. In the mean-time, some early research has been initiated on this topic, we organized a workshop at INFORMATIK 2019 on VRUs and initial projects report very interesting results on safety features for VRUs. Building upon the great success of the first two seminars, with this follow-up seminar, our goal was to once again bring together experts from all these fields from both academia and industry. The seminar focused intensively on discussions in several working groups. To kick-off these discussions, we invited three keynote talks:

- Distributed machine learning in the vehicle-to-edge continuum by Carla-Fabiana Chiasserini (Polytechnic University of Turin, IT)
- A TechCity Living lab for vehicular-based mobility services in the road by Susana Sargento (Institute of Telecommunications, PT)
- Edge-based increase of awareness and support for all traffic participants by Lars Wolf (TU Braunschweig, DE)

We finally organized the following working groups on some of the most challenging issues related to inter-vehicular communication and cooperative driving:

- Edge Computing: A multi-dimensional techno-economic outlook (i.e., latency, cost, deployment issues, etc.)
- Cooperative Driving Again: Where are we now after 2018? What about vehicular platooning: Is it still alive? What are still unsolved challenges?
- How do we support VRU detection/warning?
- Forget about V2V, we have V2C: Is Vehicle-to-Cloud the Way to Go?

References

1 Falko Dressler, Frank Kargl, Jörg Ott, Ozan K. Tonguz and Lars Wischhof, "Research Challenges in Inter-Vehicular Communication – Lessons of the 2010 Dagstuhl Seminar," IEEE Communications Magazine, vol. 49 (5), pp. 158-164, May 2011.

2 Falko Dressler, Hannes Hartenstein, Onur Altintas and Ozan K. Tonguz, "Inter-Vehicle Communication – Quo Vadis," IEEE Communications Magazine, vol. 52 (6), pp. 170-177, June 2014.

3 Onur Altintas, Suman Banerjee, Falko Dressler and Geert Heijenk, "Executive Summary – Inter-Vehicular Communication Towards Cooperative Driving," Proceedings of Dagstuhl Seminar 18202 on Inter-Vehicular Communication – Towards Cooperative Driving, Schloss Dagstuhl, Germany, May 2018, pp. 31–59.

2 Table of Contents

3 Overview of Talks

3.1 Distributed machine learning in the vehicle-to-edge continuum

Carla-Fabiana Chiasserini (Polytechnic University of Turin, IT)

Main reference Falko Dressler, Carla-Fabiana Chiasserini, Frank H. P. Fitzek, Holger Karl, Renato Lo Cigno, Antonio Capone, Claudio Casetti, Francesco Malandrino, Vincenzo Mancuso, Florian Klingler, Gianluca Rizzo: "V-Edge: Virtual Edge Computing as an Enabler for Novel Microservices and Cooperative Computing", CoRR, Vol. abs/2106.10063, 2021.
URL https://arxiv.org/abs/2106.10063

Intelligent Edge is an emerging paradigm for virtualized mobile services addressing the growing need for AI/ML at the network edge. In this context, mobility safety applications, such as collision avoidance or assisted intersection crossing for vulnerable road users, represent a use case of paramount importance, due to their enormous relevance to society. However, user safety applications requiring ultra-low latency are not the only type of service that needs to be implemented at the edge: networking functions, like virtual radio access networks (vRANs), require to be deployed at the edge as well so as to provide user-to-infrastructure connectivity. The recently proposed Virtual Edge concept looks at such complex ecosystem, and, going beyond Intelligent Edge, aims to find solutions to the challenges that virtualization at the edge poses. In the spirit of Virtual Edge, first we first tackle the dynamic configuration of heterogeneous vRANs providing connectivity to vehicles, as well as to vulnerable road users. Indeed, to fully exploit the potentiality of vRANs in non-stationary environments, an efficient mapping of the rapidly varying context to radio control decisions is not only essential, but also challenging owing to the non-trivial interdependence of network and channel conditions. Our solution, named CAREM, leverages a novel, scalable distributed learning approach, using multiple reinforcement learning agents that allow for dynamic radio resource allocation in the presence of multiple connected users and multiple available links. CAREM meets latency as well as packet loss requirements, enabling the selection of the best radio link among different, available technologies, as well as the modulation and coding scheme (MCS) to be used for packet transmission. It does so by rapidly learning the temporal evolution of the context and associating best actions thereto, based on near real-time feedback on KPI satisfaction as the channel and traffic conditions vary. To demonstrate the benefits of CAREM in real-world settings, we developed a testbed and derived extensive experimental results. Then, giving the scarcity of resources at the edge, we exploit distributed learning to realize the concept of pervasive ML and, so doing, fully leverage the resources offered by the smart city infrastructure and the passing-by vehicles. In particular, drawing on federated learning and distributed stochastic gradient descent, we propose a framework for flexible parallel learning (FPL), achieving both data and model parallelism. Thanks to a newly introduced layer and making an edge node coordinate the learning process, FPL makes distributed learning architectures able to adapt to different network topologies and, hence, flexibly use computing and energy resources in the fog. Further, we investigate how different ways of distributing and parallelizing learning tasks across the participating nodes result in different computation, communication, and energy costs. Our results, obtained using state-of-the-art deep-network architectures and large-scale datasets, show that FPL allows for an excellent trade-off among computational (hence energy) cost, communication overhead, and learning accuracy.

3.2 A TechCity Living lab for vehicular-based mobility services in the road

Susana Sargento (Institute of Telecommunications – Aveiro, PT)

In the framework of the EU project Aveiro STEAM City, researchers in the University of Aveiro and the Institute of Telecommunications, have been deploying an advanced, large-scale communications infrastructure, spread throughout the city of Aveiro, that will be at the service of researchers, digital industries, startups, scale-ups, R&D centers, entrepreneurs and other stakeholders interested in developing, testing or demonstrating concepts, products or services. Supported by state-of-the-art fiber link technology (spread across 16km in the city), reconfigurable radio units, 5G-NR radio and 5G network services, the access infrastructure covers 44 strategic points in the urban area of Aveiro, in the form of smart lamp posts or wall boxes on building facades with communications technologies, edge-based computing units and sensors. The communications infrastructure integrates a communication network with radio terminals, multiprotocol, spread throughout the city, connected by fiber optics to a data processing centre, located at Institute of Telecommunications. Buses and garbage collection vehicles have also been equipped with sensors, which currently record mobility and environmental data, making a complete live map of these parameters in the city, and providing the required data for traffic monitoring and safe driving systems. All these points combine and interconnect a set of sensors, such as mobility sensors (GPS, radars, lidars and video cameras) and environmental sensors (such as temperature, humidity, pollution) with remote data collection units throughout the city, providing enough data to support a wide range of services and applications: from IoT and internet access to citizens, to mobility and intermodal services, smart parking, assisted driving, intelligent transportation systems, environmental monitoring, distribution of information and multimedia content, emergency and safety, health services, among others. This talk dives into the Living Lab and on the vehicular, edge and sensing mechanisms researched to enable a safer mobility environment, with a focus on vulnerable users.

3.3 Edge-based increase of awareness and support for all traffic participants

Lars Wolf (TU Braunschweig, DE)

Research on Inter-Vehicular Communication (IVC) started already some decades ago. Methods to inform others about existence and actual behavior using Cooperative Awareness Message (CAM) and similar have been designed some 20 years ago. During the last decade also means to inform others about observations have been added and standardized with the Collective Perception Message (CPM), thus, increasing the awareness range, e.g., beyond corners. However, these approaches mainly focus on vehicles. Although general ideas and studies to involve Vulnerable Road Users (VRUs) into the overall scenario have been brought up more than a dozen years ago, e.g., in projects such as AMULETT, Car2Ped, and work at NTT Docomo, further research would be useful to integrate VRUs more safely into the traffic landscapes. For that, but also for mere vehicular scenarios, involvement of edge components can help to increase awareness and allow for support of dense traffic situations. Various mobility scenarios can benefit from the inclusion of edge components. However, it brings up new technical needs and concerns. For instance, the edge may and should not only relay messages from vehicles for increased awareness but aggregate several messages to improve scalability, which opens questions about when, what, how to aggregate. Moreover, as it seems now, vehicles may use various communication techniques; the same applies to VRUs as traffic participants with devices worn by humans (smartphones), integrated into protection equipment (helmets, jackets, ...), or attached to bikes/pedelecs, e-scooter, wheelchairs. Overall, real-world scenarios will be complex with many participants, using IVC and non-IVC technologies for communication, many edge components, and needing selection among & handover between them.

Remote Participants

- Ana Aguiar
Universidade do Porto, PT
- Onur Altintas
Toyota Motors North America – Mountain View, US
- Mate Boban
Huawei Technologies – München, DE
- Claudio Casetti
Polytechnic University of Turin, IT
- Wai Chen
China Mobile Research Institute – Beijing, CN
- Carla-Fabiana Chiasserini
Polytechnic University of Turin, IT
- Sinem Coleri
Koc University – Istanbul, TR
- Pedro D'Orey
University of Porto, PT
- Klaus David
Universität Kassel, DE
- Falko Dressler
TU Berlin, DE
- David Eckhoff
TUM CREATE, SG
- Gerhard Fettweis
TU Dresden, DE
- Julian Heinovski
TU Berlin, DE
- Frank Hofmann
Robert Bosch GmbH – Hildesheim, DE
- Gunnar Karlsson
KTH Royal Institute of Technology – Stockholm, SE
- Florian Klingler
Universität Paderborn, DE
- Renato Lo Cigno
University of Brescia, IT
- Ian Robin Marsh
RISE SICS – Stockholm, SE, SE
- Susana Sargento
Institute of Telecommunications – Aveiro, PT
- Michele Segata
Free University of Bozen-Bolzano, IT
- Gürkan Solmaz
NEC Laboratories Europe – Heidelberg, DE
- Christoph Sommer
TU Dresden, DE
- Peter Steenkiste
Carnegie Mellon University – Pittsburgh, US
- Hsin-Mu Tsai
National Taiwan University – Taipei, TW
- Elisabeth Uhlemann
Mälardalen University – Västerås, SE
- Lars Wolf
TU Braunschweig, DE