

# 10402 Abstracts Collection and Executive Summary

## Inter-Vehicular Communication

— Dagstuhl Seminar —

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**Abstract.** From October 3 to October 6, 2010, the Dagstuhl Seminar 10402 “Inter-Vehicular Communication” was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar are put together in this paper. The first section describes the seminar topics and goals in general.

**Keywords.** Inter-Vehicular Communication, Car-2-Car, Car-2-X, Intelligent Transportation Systems

## 10402 Executive Summary – Inter-Vehicular Communication

*Falko Dressler (Universität Erlangen-Nürnberg, DE)*

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

- eSafety applications that try to make driving safer, e.g. road hazard warning;

- traffic efficiency applications aiming at more efficient and thus greener traffic, e.g. detection of traffic jams;
- manufacturer oriented applications, e.g. automatic software updates; and
- comfort applications, e.g. automatic map updates.

While there are some similarities with fields like mobile ad-hoc networks or wireless sensor networks, the specific characteristics of vehicular networks require different communication paradigms, different approaches to security and privacy, or different wireless communication systems. For example, the nodes usually do not have severe power and form factor constraints, and they might be always on. On the other hand, due to high relative speeds, wireless connections may not be stable for a longer time period and the network density is expected to vary from sparse to very dense networks.

Another challenging issue is the efficient use of available infrastructure, such as road side units or even cellular networks. Furthermore, IVC has strong links to other research domains, e.g., geo-informatics as it requires very precise localization and precise maps or highly scalable simulations that are a requirement for analyzing traffic systems with hundreds or thousands of vehicles.

In the past, many specific solutions for IVC have been identified and now, industry and other stakeholders are already calling for standardization. Still, we believe that many important research questions have only been partially answered and the approaches discussed in the standardization bodies are based only on a minimum consensus of simplest solutions. Security and privacy, scalability, use of advanced communication patterns like aggregation, transmit power control, and optimal medium access are just a few of such issues.

The main goal of this seminar was to bring together leading researchers both from academia and industry to discuss and evaluate the state of the art and to highlight where sufficient solutions exist today, where better alternatives need to be found, and also to give directions where to look for such alternatives. Furthermore, it was the goal of this workshop to go on step beyond and identify where IVC can contribute to the basic foundations of computer science or where previously unconsidered foundations can contribute to IVC.

For example, IVC has triggered active research on reactive and dynamic security systems that do not try to provide security in a cryptographic sense at usually high costs, but create a tunable security-performance trade-off using reputation and consistency-checking mechanisms that are not unlike human and social mechanisms to estimate trust in information. It remains to be seen if such mechanisms can be generalized and be applied to future networks that will be dynamic and self-organizing in nature.

We organized four working groups on some of the most challenging issues in inter-vehicular communication:

- Fundamental Limits (Hannes Hartenstein),
- Communication Principles and Patterns (Ozan Tonguz),
- Security & Privacy (Elmar Schoch), and
- Simulation and Modeling (Martin Treiber and Christoph Sommer).

The workshop gathered a roster of highly qualified senior participants and several talented young researchers from both academia and industry, who convened to discuss issues in the listed working groups. We kept a very loose schedule with four invited speeches by leading experts in their respective domains as a starting point for each working group. Most of the time was spent in working group discussions. The key outcome of our working groups is available as a report in the Dagstuhl Seminar proceedings.

*Keywords:* Inter-Vehicular Communication, Car-2-Car, Car-2-X, Intelligent Transportation Systems

*Joint work of:* Kargl, Frank; Tonguz, Ozan K.; Ott, Joerg; Wischhof, Lars

### **10402 Report – Working Group on Fundamental Limits and Opportunities**

This working group investigated first steps towards finding a theoretical foundation for inter-vehicle communication. The main outcome is a sketch of a roadmap for future work in this direction.

*Keywords:* Inter-Vehicle Communication, Car-to-X Communication, Fundamental Limits

*Joint work of:* Hartenstein, Hannes; Heijenk, Geert; Muave, Martin, Scheuermann, Björn; Wolf, Lars

*Extended Abstract:* <http://drops.dagstuhl.de/opus/volltexte/2011/2926>

### **10402 Report – Working Group on Security and Privacy**

In the security working group, participants created an overview map of current topics in IVC security and privacy research that also includes an estimate of maturity of certain topics.

*Keywords:* IVC, C2X, VANET, security, privacy

*Joint work of:* Kargl, Frank; Buttyan, Levente; Eckhoff, David; Papadimitratos, Panagiotis; Schoch, Elmar

*Extended Abstract:* <http://drops.dagstuhl.de/opus/volltexte/2011/2927>

### **10402 Report – Working Group on Communication Patterns**

The objective of the working group communication patterns during the Dagstuhl Seminar on Vehicular Networks has been to review the current status of the communication patterns and principles and discuss the upcoming challenges the community will face in the near future. This is an executive summary of the discussions during the sessions.

*Keywords:* V2V, communication principles

*Joint work of:* Casetti, Claudio; Dressler, Falko; Eggert, Lars; Schmidt-Eisenlohr, Felix; Haerri, Jerome; Ott, Jörg; Wischhof, Lars

*Extended Abstract:* <http://drops.dagstuhl.de/opus/volltexte/2011/2928>

## Fundamental Limits of Inter-Vehicular Communications

*Hannes Hartenstein (KIT - Karlsruhe Institute of Technology, DE)*

For this talk, we were asked by the organizers of the seminar to explore what is known about fundamental limits of inter-vehicular communication. By broadening the topic to cover fundamental issues and challenges and by focusing to performance limits (and not generally covering limiting factors), we look at the impact of IVC to the vehicular traffic system as well as to the communication aspects itself. In both cases, IVC appears to be a “prime example” of ubiquitous networks. Based on reviewing selected papers and results, we identify various topics for discussion:

- i) modeling of human behavior in the context of future driver assistance,
- ii) assessment of safety applications on “maneuvering level”,
- iii) fundamental limits on “how much better would optimal traffic actually be”,
- iv) trade-offs in multi-application / multi-agent scenarios,
- v) challenges in appropriate “averaging methodology”,
- vi) practical issues of field operational tests.

In the second part of the talk, we explore fundamental issues of the communication system and identify the following for key issues:

- i) V2X channel models,
- ii) information theory for local broadcast communications,
- iii) control theory for global optimization under local and distributed observations,
- iv) a roadmap for “disruptive V2X communication technology” like getting rid of the hidden terminal problem.

*Keywords:* Limits, opportunities, inter-vehicular communication, V2X

*Joint work of:* Hartenstein, Hannes; Mittag, Jens; Schmidt-Eisenlohr, Felix

## Vehicular Networks: Principles and Applications

*Ozan K. Tonguz (Carnegie Mellon University - Pittsburgh, US)*

In this talk, we give an overview of some of the key underlying principles of inter-vehicle communications as well as some emerging applications.

We argue and show that some of the characteristics of vehicular communication + the associated propagation models may have a profound effect on higher layer performance metrics such as penetration distance of safety messages as well as end-to-end delay. This highlights the validity + significance of cross-layer design approaches in inter-vehicle communications.

We also discuss some emerging applications of inter-vehicle communications such as safety, traffic information systems, and entertainment. Such applications provide compelling evidence about the future potential of this field and its benefits: safer transportation systems, reduced congestion in urban areas (hence increased productivity + reduced CO<sub>2</sub> emissions), and a more pleasant driving experience.

## Inter-Vehicle Communication: Security & Privacy

*Elmar Schoch (Volkswagen AG - Wolfsburg, DE)*

Security and privacy are two of the fundamental problems that have to be solved before inter-vehicle communication can be deployed. Otherwise, the dependability and user acceptance of the entire system is likely to be low, because attackers may manipulate messages or track the itineraries of vehicles.

The talk comprises three parts. First, it is important to recall what we want to achieve with IVC, which is mostly safety and driver comfort functions. In particular, those applications require that drivers can trust the system. In a second part, the talk summarizes the current state of the art and the required building blocks for security & privacy in IVC. Based on this overview and the estimation how mature solutions are in each field, the talk continues by highlighting open challenges of security and privacy in IVC. Among those are flexible and tailorable solutions, large-scale security management, security evolution, and internationalization. The talk concludes with an exclamation to start research in these fields that is also practically influenced and deployable.

## IVC Modelling and Simulation

*Martin Treiber (TU Dresden, DE)*

Simulation of driver assistance systems and other ITS applications with C2C/C2X communication components requires the tools of the trade of two different fields:

Transport of data (communication models), and transport of vehicles (traffic flow models). The focus depends on the application: Generally, safety-related driver assistance systems require detailed communication models. Conversely, the traffic flow dynamics become more relevant for applications to improve efficiency.

In this contribution, I describe three applications of the latter category: (i) Congestion warning system, (ii) traffic flow assistant, and (iii) traffic-light assistant. In all cases, information generated by equipped vehicles on an event-oriented basis (e.g., when detecting a traffic jam) must be transported upstream to another equipped vehicle for which this information may be useful.

Two propagation strategies are considered: Longitudinal hopping across relay vehicles in the same direction, and transversal hopping (store-and-forward) where vehicles on the opposite direction serve as information carriers.

In a first step, we develop analytical information models for both propagation strategies. In a second step, the analytical model predictions are tested against microsimulations and real trajectory data. It turned out that, in spite of the very crude approximations, there were little discrepancies for the relevant case of low penetration rates. Moreover, the full traffic-flow microsimulation showed that the proposed applications would be operative for penetration rates as low as 1-2%.

*Keywords:* Traffic flow models, car-following models, penetration rate, traffic-light assistant, congestion warning

*Joint work of:* Treiber, Martin; Kesting, Arne

## IVC Simulation and Modeling

*Christoph Sommer (Universität Erlangen-Nürnberg, DE)*

This talk presents approaches to three of the central issues that are plaguing IVC Simulation and Modeling at this time: How can a researcher integrate into one simulation the huge variety of models – each of which can only cover a sub-domain of the current state of the art? Can such an approach pave the way to modeling truly heterogeneous networks and scenarios, for which protocols ameliorating, e.g., low market penetration, can then be put in place? Finally, it presents an exemplary way of abstracting away from fine-grained models while still capturing relevant effects and maintaining the explanatory power of the model.

## Trends behind non-uniform Patterns in Vehicular Networks

*Jerome Haerri (EURECOM, FR)*

Inter-vehicular communication is significantly influenced by vehicular mobility and environmental aspects unique in shape and intensity. Nevertheless, most of the developed communication principles have been thought and evaluated with average conditions in mind. Considering the large spatial and temporal variance of most of the mobility, topological and connectivity properties around average

values, such vehicular communication principles have a high probability to be unadapted to instantaneous conditions.

In this short talk, we illustrate the non-uniform patterns experienced by vehicular networks, such as link duration and vehicular density, and discuss some trends towards using them as an asset instead of a drawback for the design of efficient communication principles for vehicular networks. We notably take the case of the distribution of infrastructure in an urban area. We model the user satisfaction by having a connection to an 802.11p access point (AP) and the provider's satisfaction as the minimization of the required infrastructure. We illustrate that by selecting access point locations depending on a defined context instead of a maximum coverage, we can provide a joint user-provider satisfaction optimum increased by a factor of two with half of the required APs. Generalizing, non-uniform connectivity patterns, such as link duration, could also be investigated for vehicles to provide multi-hop relaying capabilities as coverage extension for access points, and potentially further reducing the required APs.

*Keywords:* Communication principles, spatio-temporal, link duration, density, AP distribution, user satisfaction

*Joint work of:* Cataldi, Pasquale; Härrri, Jérôme

## Impact of Packet Loss on Crash Avoidance Applications

*Mahbub Hassan (Univ. of New South Wales, AU)*

Inter-vehicle communication is unreliable where we can expect packet losses. These packet losses may impact the performance of vehicular safety applications such as crash avoidance warning systems. In this paper, we examine the impact of packet loss on such crash avoidance systems through a series of practical intersection traffic scenarios (see self-explanatory Figures 1-11). Table 1 summarizes the outcome from these scenarios. These illustrative scenarios show that a single packet loss may have serious impact for certain scenarios.

*Keywords:* Inter-vehicle communications, crash avoidance, packet loss

*Joint work of:* Hassan, Mahbub; Wang, Zhe