# Guest Editorial Special Section on Vehicular Networks and Communication Systems: From Laboratory into Reality

WIRELESS vehicular communications has been identified as a key technology for increasing road safety and transport efficiency, as well as for providing Internet access on the move to ensure wireless ubiquitous connectivity. It is clear that vehicular communications and networking will be the cornerstones of the future cyber–physical system, which will significantly change our daily lives.

Researchers have also realized the great potential of using vehicular wireless communications to improve transportation efficiency and to provide comfort and convenience to drivers and passengers. It is increasingly clear that enabling a rich set of vehicular applications requires that vehicular wireless networking technology be developed beyond the state of the art. As technologies mature over time, different classes of vehicular applications will be realized: initially, convenience, infotainment, and driver-assistance applications that have relatively low latency, positioning, reliability, and coverage requirements; and, ultimately, active safety and cooperative collision-avoidance applications because their technical requirements tend to be more stringent. By aggressively addressing the challenges and opportunities for creating direct, multihop (of vehicular ad hoc network (VANET) nature), and opportunistic communications (of delay-tolerant network nature) to, from, and between vehicles, we believe that the academic and research community can assist the automotive and telematics industry in realizing their goals of rendering a full set of services to vehicle drivers and passengers.

Over the past few years, the U.S., Europe, Japan, and several other regions have been actively involved in academic research and industry development activities, where the technical and commercial benefits of vehicular wireless communication systems, such as dedicated short-range communications or VANETs, are being explored. Several research projects and industry consortiums (including the Intelligent Vehicle Initiative and Vehicle Safety Communication Project in the U.S., the Car 2 Car Communication Consortium and DRIVE C2X in Europe, and the Advanced Safety Vehicle project in Japan) are closely following the progress of worldwide academic research, industry development, and international standards activities.

To encourage the interoperability between vehicles of different makes, brands, and generations, international standards for radio technologies, communication protocols, and common message sets are of fundamental importance. The activities currently undertaken by IEEE, the Society of Automotive Engineers (SAE) standard society, and the European Telecommunications Standards Institute (ETSI) include 1) the IEEE 802.11p standard and 2) the IEEE 1609 and SAE J2735 standards, as well as ETSI EN 302 663, among others.

This Special Section includes nine technical papers that mainly deal with vehicular wireless networks, covering a rich variety of research topics ranging from vehicular channel modeling to safety application design. These nine papers were selected from a total of 46 submissions to our Special Section. We were fascinated by such a large number of submissions. Clearly, the popularity of this topic cannot be underestimated.

The first paper, "Automatic Emergency Braking: Realistic Analysis of Car Dynamics and Network Performance," studies the effect of vehicle-to-vehicle (V2V) communication techniques on adaptive cruise control emergency braking through detailed highway simulations. It shows that congestion of the communication network can be addressed through application-level aggregation techniques. It also shows that the increased situational awareness obtained through V2V communications creates benefits such as smoother braking and reduced accident rates, even if only 5%–10% of vehicles are equipped with the system. This result calls into question the view that V2V communications requires almost full market penetration to show safety gains.

The second paper, "Statistical Beaconing Congestion Control for Vehicular Networks," addresses the issue of controlling the load on the radio channel in vehicular networks. Since, in vehicular networks, all vehicles are supposed to periodically send out status messages that indicate, for example, the speed and direction of the vehicle, the aggregated load on the channel needs to be controlled to avoid congestion of the radio channel. In this paper, an approach based on controlling the transmit power is proposed that only requires local information and limited feedback. Results based on a hybrid network and traffic simulator show the effectiveness of the approach.

In the third paper, "LIMERIC: A Linear Adaptive Message Rate Algorithm for DSRC Congestion Control," the issue of controlling the load on the radio channel is addressed from the perspective of controlling the rate at which the vehicles send out their status messages. The LIMERIC approach shows excellent convergence properties in both theory and simulations.

Digital Object Identifier 10.1109/TVT.2013.2286434

In particular, it is able to converge to the desired channel load and achieves local and global fairness, which is a property that is very important in safety-critical scenarios such as vehicular environments.

In the fourth paper, "Performance and Reliability Analysis of IEEE 802.11p Safety Communication in a Highway Environment," the theoretical aspect of IEEE 802.11p medium-access-control contention protocol was explored. In particular, the authors look into the enhanced distributed channel access mechanism of the IEEE 802.11 standard and analyze the 802.11p safety-critical broadcast in a VANET environment. This piece of work improves the existing work by taking several new aspects into design consideration. Extensive performance evaluations based on the NS-2 simulator help to validate the accuracy of the proposed model.

Security is always a major technical challenge faced by vehicular network researchers. The group key management (GKM) is expected to play an important role, but the legacy GKM schemes are not cost effective and adequate for use in the vehicular environments due to its complexity. To address this issue, the fifth paper, "Subscription-Period-Aware Key Management for Secure Vehicular Multicast Communications," proposes a new GKM scheme called Subscription-Period-Aware Key Management (SPKM), for cost-effective and secure vehicular multicast group rekeying. Through simulations, it is shown that the proposed SPKM scheme can greatly reduce the communication, computation, and storage complexity in the process of multicast group rekeying from $O(\log N)$ to $O(1)$.

In the sixth paper, "Correlation and Spectral Properties of Vehicle-to-Vehicle Channels in the Presence of Moving Scatters," a V2V channel model is established by assuming a typical propagation scenario in which the local scatters move with random velocities in random directions. Based on the proposed model, several V2V channel characteristics such as autocorrelation function, power spectral density, and the Doppler spread of the channel could be derived and further validated using available measurement data. This proposed V2V channel model could flexibly cover a number of communication scenarios, including fixed-to-vehicle and fixed-to-fixed scenarios in the presence of both fixed and mobile scatters.

In the seventh paper, "An Impulse Response Model and $Q$-Factor Estimation for Vehicle Cavities," the authors look into the wireless channel model of in-vehicle environments. This group of authors shows that reverberation chamber models can be applied to the impulse response of the in-vehicle environment. However, owing to the differences between the vehicle cavity and a standard reverberation chamber, it is found that the cavity $Q$ factor is best estimated using a maximum-likelihood approach with an inverse discrete Fourier transform. The temporal correlation properties of the channel are also estimated based on the assumed motion of the occupants of the vehicle.

In the eighth paper, "Flexible, Portable, and Practicable Solution for Routing in VANETs: A Fuzzy Constraint Q-Learning Approach," the authors propose PFQ-AODV, which is a Portable VANET routing protocol that learns the optimal route by employing a fuzzy-constraint Q-Learning algorithm based on AODV. Based on an evaluation of each wireless link, the proposed protocol learns the best route using the route request messages and hello messages. The flexibility, portability, and effectiveness of the proposed protocol is shown by using both computer simulations and real-world experiments.

Last but not least, the last paper, "Context-Aware Driver Behavior Detection System in Intelligent Transportation Systems," focuses on developing a nonintrusive driver behavior detection system using a context-aware mechanism to detect abnormal behaviors exhibited by drivers, as well as to warn other vehicles on the road. In particular, a five-layer context-aware architecture is proposed, which is able to collect contextual information about the driving environment, perform reasoning about certain and uncertain contextual information, and react upon that information. Using synthetic data, the proposed model is validated as a good approach to detect driver behaviors.

We would like to thank all the reviewers for their help and support. Moreover, this team of guest editors would also like to show their appreciation for the great support from the Editors-in-Chief, Prof. Weihua Zhuang and Prof. Michael Fang in our organization of this Special Section. Finally, we hope that you, the readers, will find this Special Section interesting and inspiring for your academic research or industry work.

FAN BAI, *Guest Editor*
General Motors Research
Warren, MI 48090 USA

HANNES HARTENSTEIN, *Guest Editor*
University of Karlsruhe
76131 Karlsruhe, Germany

MARCO GRUTESER, *Guest Editor*
Department of Electrical and Computer Engineering
Rutgers University
New Brunswick, NJ 08901 USA

ROBIN KRAVETS, *Guest Editor*
Department of Computer Science
University of Illinois in Urbana–Champaign (UIUC)
Urbana, IL 61801 USA

TAO ZHANG, *Guest Editor*
Cisco Systems
San Jose, CA 95134 USA

DANIEL D. STANCIL, *Guest Editor*
Department of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27606 USA

**Fan Bai** received the B.S. degree in automation engineering from Tsinghua University, Beijing, China, and the M.S. and Ph.D. degrees in electrical engineering from the University of Southern California, Los Angeles, CA, USA.

Since 2005, he has been with the Electrical and Control Integration Laboratory, Research and Development and Planning, General Motors Corporation, Detroit, MI, USA, where he is currently a Senior Researcher. He is also serving as a Ph.D. supervisory committee member with Carnegie Mellon University, Pittsburgh, PA, USA, and the University of Illinois–Urbana-Champaign, Champaign, IL, USA. He is the author of 60 book chapters and many conference and journal papers. His research interests include the discovery of fundamental principles and the analysis and design of protocols/systems for next-generation vehicular ad hoc networks for safety, telematics, and infotainment applications.

Dr. Bai served as the Technical Program Cochair for the First IEEE International Symposium on Wireless Vehicular Communications in 2007, the Second International Workshop on Mobile Vehicular Networks in 2008, and the Eighth and Ninth ACM International Workshops on Vehicular Inter-Networking in 2011 and 2012, respectively. He serves as an Associate Editor for the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY and the IEEE TRANSACTIONS ON MOBILE COMPUTING and serves as a Guest Editor for the IEEE WIRELESS COMMUNICATION MAGAZINE, the IEEE VEHICULAR TECHNOLOGY MAGAZINE, and the *Elsevier Ad Hoc Networks Journal*. He received the Charles L. McCuen Special Achievement Award from General Motors Corporation in 2006 for his technical contributions to vehicular networks.

**Hannes Hartenstein** (M'01) received the Diploma in mathematics and the Ph.D. degree in computer science from Albert Ludwigs University of Freiburg, Freiburg, Germany.

He was a Senior Research Staff Member with NEC Europe. From 2001 to 2003, he was NEC's Project Leader for the FleetNet—Internet on the Road project and was involved in the Network on Wheels (NOW) project during 2004–2008. He is currently a Full Professor for decentralized systems and network services and the Director of Steinbuch Centre for Computing with the Karlsruhe Institute of Technology, Karlsruhe, Germany. He participated in the European Union Seventh Framework Programme (EU FP7) project PRE-DRIVE-C2X and is now actively involved in the EU FP7 project DRIVE-C2X. He is a coeditor of *VANET: Vehicular Applications and Inter-Networking Technologies* (Wiley, 2010), together with K. P. Laberteaux. His research interests include mobile networks, virtual networks, and information technology management.

Dr. Hartenstein is a member of the Scientific Directorate of the Leibniz Center for Informatics, Schloss Dagstuhl. He was a General Cochair and a Technical Cochair for various Association for Computing Machinery and IEEE workshops, conferences, and symposia related to wireless vehicular networks.

**Marco Gruteser** (M'12) received the Vordiplom from Darmstadt University of Technology, Darmstadt, Germany, in 1998 and the M.S. and Ph.D. degrees in computer science from the University of Colorado, Boulder, CO, USA, in 2000 and 2004, respectively.

He held visiting positions at Carnegie Mellon University, Pittsburgh, PA, USA, and the IBM T. J. Watson Research Center, Yorktown Heights, NY, USA. He is currently an Associate Professor of electrical and computer engineering a member of the Wireless Information Network Laboratory with Rutgers University, New Brunswick, NJ, USA. He is a pioneer in the area of location privacy and is recognized for his work on connected vehicle applications. Beyond these topics, his more than 100 peer-reviewed articles and patents spanning a wide range of wireless and mobile systems and pervasive computing issues.

Dr. Gruteser has been elected Treasurer of Association for Computing Machinery (ACM) SIGMOBILE. He has served as a Technical Program Committee Cochair and a Vice Chair for the IEEE International Conference on Pervasive Computing and Communications, the ACM Conference on Security and Privacy in Wireless and Mobile Networks, and the IEEE Vehicular Networking Conference. He also served on the program committees of numerous ACM and IEEE conferences, including the ACM Annual International Conference on Mobile Computing and Networking (ACM MobiCom), the ACM International Conference on Mobile Systems, Applications, and Services, the ACM International Conference on Pervasive and Ubiquitous Coding, and the IEEE Conference on Computer Communications. He has served on the editorial boards of the IEEE TRANSACTIONS ON MOBILE COMPUTING and *Elsevier Computer Networks*. He received the National Science Foundation Early Career Development (CAREER) Award, the Schwarzkopf Prize from the Industry/University Cooperative Research Center Association for the ORBIT wireless test-bed team, the Best Paper Award at ACM Mobicom in 2010, 2011, and 2012, and the Board of Trustees Research Fellowship for Scholarly Excellence that honors Rutgers University's most distinguished young faculty members. His work has been repeatedly featured in numerous media outlets including *National Public Radio*, the *MIT Technology Review*, the *New York Times*, and *CNN TV*.

**Robin Kravets** received the B.S. degree in computer and information science from the University of Massachusetts, Amherst, MA, USA, in 1989; the M.S. degree in computer science from the University of California, Los Angeles, CA, USA, in 1993; and the Ph.D. degree from the College of Computing, Georgia Institute of Technology, Atlanta, GA, USA.

She is currently an Associate Professor with the Department of Computer Science, University of Illinois in Urbana–Champaign, Champaign, IL, USA. Her research interests include mobile computing and communications. She is currently the leader of The Mobius Group, which is dedicated to research for seamless communication in mobile computing. She is a member of the Grace Project, which aims to provide a cross-layer solution to global resource management. She is also a member of the GAIA Project, which focuses on research in active spaces for ubiquitous computing.

**Tao Zhang** (F'11) has been serving on the industry advisory boards for several research organizations and has been an Adjunct Professor at multiple universities. He is currently the Chief Scientist for Cisco Connected cars with Cisco Systems, San Jose, CA, USA. For over 25 years, he has been directing research and product development in mobile and vehicular networks. He is a coauthor of *Vehicle Safety Communications: Protocols, Security, and Privacy* (Wiley, 2012) and *IP-Based Next Generation Wireless Networks* (Wiley, 2012). He is the holder of 33 U.S. patents covering areas such as security, mobility management, information dissemination, and energy-conversing protocols for wireless, mobile ad hoc, sensor, and vehicular networks.

Dr. Zhang was a founding member of the Board of Directors of the Connected Vehicle Trade Association in the U.S. He is the Chair of the IEEE Communications Society Technical Committee on Vehicular Networks and Telematics Applications. He has been serving on editorial boards or as a Guest Editor for a number of leading technical journals.

**Daniel D. Stancil** (F'04) received the B.S. degree in electrical engineering from Tennessee Technological University, Cookeville, TN, USA, in 1976 and the S.M., E.E., and Ph.D. degrees from the Massachusetts Institute of Technology, Cambridge, MA, USA, in 1978, 1979, and 1981, respectively.

From 1981 to 1986, he was an Assistant Professor of electrical and computer engineering with North Carolina State University, Raleigh, NC, USA. From 1986 to 2009, he was an Associate Professor and then a Professor of electrical and computer engineering with Carnegie Mellon University, Pittsburgh, PA, USA. Since 2009, he has been with Department of Electrical and Computer Engineering, North Carolina State University, where he is currently the Alcoa Distinguished Professor and the Department Head. His research interests include channel models for wireless communications and other topics in applied electromagnetism.

Dr. Stancil was a President of the IEEE Magnetics Society.