Scanning the Issue: Vehicular Communications

The case for research, development, and deployment of vehicular communications is a strong one. Arguments are made and elaborated on in numerous papers, including those that make up this Special Issue and our Point of View feature in the 2010 July issue of the PROCEEDINGS [1]. We will therefore be brief here and just recount some of the more compelling reasons for why we should care about this technology.

Consider the question "What was the second most common cause of death for 5—29 year olds in 2002?" If this question was posed in a more general context than here, we doubt that many would know the correct answer: road traffic injuries, according to a World Health Organization (WHO) report [2]. We can quote many other alarming statistics from [2], including

- 1.4 million dead and up to 50 million injured on a yearly basis
- total estimated economic cost of USD 518 billion, of which the estimated USD 65 billion affecting low-income countries exceeds the amount received in development assistance.

Clearly, we, humans in general and engineers in particular, should do something to reduce these appalling numbers. Reducing the number of accidents will have many other positive effects including more efficient use of fuel, time, and other resources, i.e., contribute to make the transport system sustainable.

Vehicular communications is defined in this Special Issue as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, collectively referred to as V2X communications. With infrastructure in V2I, we mean road infrastructure, such as traffic light, street signs, etc., which is not to be confused with communications infrastructure, such as access points (APs) or base stations. V2X communications is an enabling technology for cooperative traffic safety systems, i.e., systems in which vehicles and road infrastructure cooperates to avoid or mitigate the effects of accidents. For obvious reasons, vehicular communications needs to be wireless. Although free-space optical systems, e.g., infrared communications, are used, radio is dominating. Many existing radio systems, such as traditional cellular and satellite systems, can and are used for vehicular communications. However, new technology is emerging to cover the case when the supported latency or coverage of existing technology is not good enough. The new technology is based on direct communications without the aid of communication infrastructure, e.g., base stations, satellites or access points.

In this Special Issue, we will focus our attention on key problems in these new systems: modeling of radio channels, physical and medium access techniques, simulation methods, and standardization of V2X systems. Admittedly, this is not a comprehensive coverage of the field, since we are not treating important problems such as security, privacy, and routing in V2X networks. However, a prudent pruning of the scope of the Special Issue was needed for space constraints.

The nine papers that make up this Special Issue will follow a top-down-top approach in which we first explore the current standardization effort carried out by primarily the IEEE and the European Telecommunications Standards Institute (ETSI), then we will dive down to issues related to the vehicular radio channels, and work our way up the communication stack by discussing the physical and medium access layers, and finish by describing modeling and simulation approaches.

Standards are crucial for cost-efficient deployment of V2X technology. The first paper by Kenney describes in detail the 75 MHz-wide dedicated spectrum allocation in the US and the standards IEEE

802.11p, IEEE1609.1—1609.4, SAE J2735, and SAEJ2945-1, that make up the bulk of the V2X protocol stack in the US, also known as Wireless Access in Vehicular Environments (WAVE). Most of these standards have been published within the past 18 months and are reaching a certain level of a maturity. However, the IEEE 1609.2 (Security Services) and SAE J2945-1 (Minimum Performance Requirements) standards are first expected in late 2011.

The second paper by Ström briefly describes the European Intelligent Transport System (ITS) architecture, which has been developed mainly by ETSI. This architecture is, in general, different from WAVE. However, both architectures are based on IEEE802.11p, which is good news for the chip and vehicular manufactures. The focus of Ström's paper is on European spectrum allocation, which is less generous and only partly overlapping with the United States allocation, and ETSI's profile of IEEE 802.11p, called ITS-G5. A common conclusion from Kenney's and Ström's papers is that future work on congestion control is required (which is the topic of the paper by Sepulcre et al. described below).

The third paper by Mecklenbräuker et al., describes the key characteristics of V2X channels, i.e., shadowing by other vehicles, high Doppler shifts, and the inherent non-stationarity, which all have a major impact on transmission reliability and latency. The paper provides an overview of the existing V2V and V2I channel measurements, reviews currently available vehicular channel models, and point out their respective merits and deficiencies. Antenna and their placement on the vehicles, which will have a major impact on the achievable performance, are discussed. The paper is concluded by exploring the implications of V2X channels and antennas on wireless system designs in general and on the IEEE 802.11p physical (PHY) layer in particular. The paper points out that further work on channel measurements and channel modeling is needed, as V2X channels are not completely understood. Moreover, a key conclusion is that the PHY layer should be designed with respect to the properties of the propagation channels, in particular to the time-varying joint Doppler and delay spread. In this respect, the 802.11p PHY layer would profit, e.g., from a better pilot distribution and the introduction of multiple transmit and receive antennas.

The fourth paper by Alexander et al. presents the results from extensive V2X field trial campaigns conducted with 802.11p equipment in Australia, Italy, Germany, Austria, and the United States, covering over 1,100 km of driving in a wide variety of physical environments. The field trials show that commercial off-the-shelf (COTS) equipment sometimes fail to provide good enough performance, especially in non line-of-sight propagation environments. However, much better results were achieved with 802.11p-compliant equipment that employs more sophisticated channel estimation and tracking. Hence, the Alexander et al. and the Mecklenbräuker et al. papers are in complete agreement about the importance of this point. Moreover, the paper presents delay and Doppler spreads statistics based on the accumulated field trial measurements.

The fifth paper by Sturm and Wiesbeck makes a case for a joint radar and communication (RadCom) system. Together with cameras and lidars (Light Detection And Ranging), radars are the most commonly used type of sensor on vehicles. A RadCom system could potentially solve the essential tasks of environmental sensing and V2X communications more efficiently than two separate systems. The authors propose waveform designs, suitable for simultaneously performing both data transmission and radar sensing, and discuss a variety of possible radar processing algorithms. Multiple antenna techniques for direction-of-arrival estimation are also considered.

The sixth paper by Sepulcre et al. starts from the observation that, if countermeasures are not undertaken, the V2X radio channel will most likely be saturated even under normal vehicular traffic conditions. Radio channel congestion causes unstable V2X communications, thus putting the whole cooperative vehicular system concept at risk. In the paper, Sepulcre et al. surveys and classifies various decentralized methods to control the load on the radio channel and to ensure each vehicle's capacity to detect and communicate with the *relevant* neighboring vehicles. A particular focus is on approaches based on transmit power and rate control. Open research challenges that are imposed by different application requirements and potential existing contradictions are also discussed at the end of the paper.

Cost-efficient design and analysis of V2X systems requires that computer simulations are complementing field trials. In fact, some design tasks are simply not feasible without efficient and accurate computer simulations, due the cost and time required by field trials. The final three papers of this Special Issue address the trade-off between simulation accuracy and efficiency from different perspectives.

The seventh paper by Giordano et al. propose a method for classifying the propagation situation between two nodes using a reverse geocoding algorithm based on a digital map and the nodes' geographical positions. The method, named CORNER, estimates the presence of buildings and obstacles along the signal path using information extrapolated from urban digital maps. The classification, into line-of-sight (LOS) and two types of non line-of-sight (NLOS) propagation, can be used with any channel models that are tailored to these situations. The authors validate CORNER (with a specific set of path-loss models) by comparing simulations with on-the-road experiments. The results indicate that CORNER is able to predict the network connectivity with high accuracy.

The eighth paper by Reichardt et al. addresses how the interaction between antennas, vehicles, and the propagation environment can be captured in a computer simulation tool. As stressed earlier in this Special Issue, multiple antennas are important for improving V2X communication performance. However, finding the optimal antenna configuration is a difficult task. A possible solution is to use prototypes and measurement campaigns, but this is expensive, time consuming, and has problems with repeatability. As an alternative, the authors describe a tool which uses environment and vehicular traffic models together with a 3D ray-tracing algorithm to calculate the multipath propagation, including the antennas, between the transmitters and receivers. This tool enables virtual driving through arbitrary scenarios and is therefore called "Virtual Drive." It is shown in the paper that the tool agrees well with V2V channel measurements in an urban and a highway scenario. The tool can also be used for radar applications.

The ninth paper by Mittag et al. is concerned with merging network and link simulators with realistic channel models. Many existing V2X communication studies have been conducted using either network or physical layer simulators; both approaches are problematic due to oversimplified modeling. Network simulators typically abstract physical layer details (coding, modulation, radio channels, receiver algorithms, etc.) while physical layer ones do not consider overall network characteristics (topology, network traffic types and so on). To overcome these shortcomings the authors present the integration of a detailed physical layer simulator into the popular NS-3 network simulator, with the aim to allow for more accurate studies on cross-layer optimization. The authors exemplify this approach by integrating an IEEE 802.11p physical layer simulator into NS-3 and validate this against an IEEE 802.11 wireless testbed. The integrated simulator is made available on-line for the benefit of the research community.

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Erik Ström, Hannes Hartenstein, Paolo Santi and Werner Wiesbeck, Guest Editors

References

[1] Erik G. Ström, Hannes Hartenstein, Paolo Santi, and Werner Wiesbeck. "Vehicular communications: Ubiquitous networks for sustainable mobility." Proceedings of the IEEE, vol. 98, no. 7, pp. 1111–1112, July 2010.

[2] Margie Peden, Richard Scurfield, David Sleet, Dinesh Mohan, Adnan A. Hyder, Eva Jarawan, and Colin Mathers, editors. "World report on road traffic injury prevention." World Health Organization, Geneva, 2004
http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/en/
[Accessed March 2011]