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Point of View

Vehicular Communications: Ubiquitous Networks for Sustainable Mobility

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Vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications are enabling technologies for a host of applications, ranging from infotainment and web browsing to cooperative driving for enhanced traffic safety and efficiency. The latter two application areas, traffic safety and efficiency, address the issue of sustainable mobility and are high on the political agendas around the world. This is for good reasons, since traffic volumes are projected to increase with the corresponding risk of increased number of traffic jams, increased emissions and natural resource consumption, and increased number of injured and killed. The International Energy Agency reports for the year 2008 a global vehicle fleet of 800 million vehicles and predicts more than 2 billion vehicles by the year 2050. In a recent WHO and World Bank report it is stated that, without appropriate action, road injuries are predicted to be the third leading contributor to the global burden of disease. V2V and V2I based ubiquitous networking, collectively referred to as V2X communications, is one of the engineering community's major contributions to address this gloomy prediction.

V2V communication refers to communication between road vehicles (cars, trucks, motorcycles, etc.) without involving a central control unit (as the case would be with traditional cellular systems). Current standardization of V2V communication is based on wireless local area network (WLAN) technologies (most notably IEEE 802.11p and IEEE 1609). The appeal of V2V communication is the potential for low-latency communications, which is important for safety-related applications, and the avoidance of (traditional cellular) coverage problems. V2I communications refer to communication between road users and road side equipment, again based on short or medium range communication technology. V2I communications have the potential to considerably increase scalability of vehicular networking protocols and to ease coordination between vehicles, through the deployment of a relatively cheap, not necessarily dense, infrastructure. Concerning cost of road side equipment, it is envisioned that wide adoption of IEEE 802.11p-based technology should significantly contribute to cost reduction.

Already four decades ago, the idea of using short range wireless communication for "reduction of road traffic congestion, reduction of exhaust fumes caused by traffic congestion, prevention of accidents, and enhancement of public and social role of automobiles" was pursued in the Japanese CACS project. In the 1980s, the "Programme for European Traffic with Highest Efficiency and Unprecedented Safety" (PROMETHEUS) stimulated research and development for mobile communication for motor vehicles in Europe. The 1990s showed astonishing and remarkable results in automatic driving, most prominently with the San Diego demonstration of the US National Automated Highway System Consortium. And in the last decade, research and development in the area of vehicular communication was on an exceptional high activity level and shaped by the availability and low cost of wireless local area network technology and global navigation satellite system receivers and turned the focus again to driver assistance. In addition, spectrum was allocated for the exclusive use of V2V and V2I communication in various regions of the world.

Where are we today? What is going to happen next? Our thesis is that vehicular communication networks will represent a prime example of ubiquitous networks of embedded systems – if we are able to master the complexity associated with unreliable communication channels, massively distributed systems, and convincing predictions on the resulting benefit for society. The advances of the last decades have provided us with a variety of technical solutions of which a number is currently standardized at the IEEE. However, everyone involved in setting up a real-world proof of concept or field operational test reports on the tremendous efforts that still are needed to manage, operate, understand and optimize these type of networks – and those networks are today typically only of a size of a few hundred vehicles.

Let us briefly screen various challenges in a top-down approach. To assess the benefit for society, one has to acknowledge the fact that for efficiency aspects, cooperation not only between vehicles but between vehicles and infrastructures like traffic control devices or power grids (for hybrid and electrical vehicles) needs to be considered. In short: the impact of vehicular communications to intelligent transportation systems needs to be quantified. In case of safety-critical applications, an assessment is a non-trivial task since safety critical events are – fortunately for us as participants of the transportation system – rare events. And, of course, an analysis is complex because it has to take the human behavior into account – and we do not know today how drivers will make use of this new technology.

In any case, the engineering community will be confronted with several questions: what performance will the communication and networking technology offer? Will the technical basis be good enough to make all those projected safety and efficiency applications a reality? While significant progress has been made – look at the use of geographic information for data packet forwarding, the IEEE 802.11p and 1609 standards activities, the ISO CALM architecture to name only a few – there are various fundamental technical challenges to be addressed. These challenges, which can be seen as related to the Intel CTO's vision of "a thousand radios per person," include characterization of the radio channels in vehicular environments, design of distributed medium access techniques for low-latency, high-reliability communications, and addressing the poor scaling behavior of ad-hoc networks (communication performance is reduced as the number of communication nodes increase). On a fundamental level, the key difference to existing communication networks is given by the differing communication pattern: communicating nodes will primarily use "local broadcasts" to send information to all nodes in a geographic neighborhood – and all nodes might send out those local broadcasts on a common channel. The classical challenge of computer and communication networking is turned into its most extreme form: provision of reliable communication (it might be for safety-of-life) given highly unreliable communication conditions.

On a methodological side, we have to accept that those vehicular communication networks are not there – yet. And if they are, we still might not be able to do every experiment we would like to do. Thus, simulation remains an important means for research and development in this exciting area. We believe that also in the field of simulation of vehicular communication we should clearly go beyond the current state-of-the-art: we need better ways for collaborative simulations that allow experts from various domains to work together in a virtual environment and to combine models that allow composition across layers and functional domains. As an example, we might want to integrate very accurate, microscopic vehicular traffic simulators with packet-level network simulators to evaluate not only vehicles' ability to communicate with each other, but also the effects of possible vehicular applications (e.g., smart route planning) taking advantage of such communication capabilities on the vehicular traffic in terms of, e.g., reduced travel time.

In an upcoming special issue of the IEEE Proceedings on vehicular communications, we will present a thorough treatment of radio propagation, coding and modulation, and medium access issues as well as a holistic view on modeling and simulation of V2V and V2I communications.