GUEST EDITORIAL

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Emerging Research in Connected Vehicles

The field of Connected Vehicles is a multidisciplinary field involving transportation, automotive, information technology, communications, electronics, media, energy, security, and privacy. Connected Vehicle technology leverages recent advances in sensing and communication to transmit information both between vehicles (V2V) and between vehicles and infrastructure (V2I) with the ostensible benefits of making driving safer, improving mobility, reducing environmental pollutants (e.g. greenhouse gases), and reducing maintenance costs. With the ability for communication among vehicles, each vehicle acts as a moving sensor providing information to other vehicles and infrastructure. By leveraging location information from neighboring vehicles, a vehicle can build situational awareness of other vehicles for automated crash avoidance. Vehicles can also transmit hazard situations to other drivers that are not readily visible due to weather or obstructed line of sight to prevent accidents. Vehicles can also provide congestion and location information to traffic lights for optimum signaling thereby obviating the need for road sensors, which can be very expensive. Finally, with communication between vehicles and traffic control infrastructure, queuing at traffic lights can be minimized thereby reducing greenhouse gas emissions and saving fuel.

While in concept these applications are very attractive, and some pilot programs have demonstrated their achievability, extensive research and development is necessary in communications, sensing, and infrastructure development for transforming our transportation infrastructure to support Connected Vehicles. Research is required in several different areas including: 1) Developing and standardizing reliable communication technologies and interoperability requirements for Connected Vehicles; 2) Data Management, Privacy, and Security; 3) Creation of algorithms for managing traffic, avoiding collisions, and other vehicular tasks; 4) Understanding social and user behaviors in the context of Connected Vehicles.

The successful implementation of Connected Vehicles is predicated on a reliable communication infrastructure. This communication will occur among a heterogeneous set of vehicles as well as infrastructure elements. Protocols and communication standards are necessary for V2V and V2I communication to ensure universal acceptance by vehicle and infrastructure vendors. This work requires coordination among international standards bodies to provide for the seamless mobility of vehicles from country to country. Standards are also required in the design of electronic equipment that enables the collection and processing of V2V and V2I data—consider the need for interoperability between vehicles or traffic signaling equipment of different manufacturers. In the paradigm of Connected Vehicles, very large volumes of data will be generated that will need to be distributed across the landscape. With over 250 million vehicles in United States alone and 20GB of data generated per vehicle per hour, the task of collection, analysis, aggregation, and storage of this data will be an enormous challenge. We will need to ensure that data is quickly analyzed, aggregated, filtered, and stored for further analysis. We need to develop software that can analyze data in the field as well as ensure adequate bandwidth is available to transmit data short distances for use in the field and long distances for storage and analysis.

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Digital Object Identifier 10.1109/MITS.2015.2408136
Date of publication: 20 April 2015

cyber-physical systems driven by telematics, which is the blending of computers and wireless telecommunications, and advanced analytics. Vehicles can receive command-and-control messages from other vehicles, infrastructure (traffic signals), vehicle manufacturers, maintenance services, and even law enforcement. Telematics will form the backbone for innovations in Connected Vehicles. However, if security is not implemented correctly, the same applications that are expected to improve safety, reliability, and efficiency can be used for to launch attacks that can cause collisions, slow traffic, re-route traffic, or disable vehicles. Cars already have an in-built complex communication network with an on-board computer managing intra-vehicle tasks. Adding telematics exposes these systems to external cyber security threats. There are several crucial areas that we need to consider for security including security of the network within the vehicle, security of the infrastructure elements (e.g., traffic lights), encryption of all communication on the cloud, and building robust authentication schemes to prevent malicious actors from operating in the network. Finally, as personal devices such as laptops, smartphones and wearable devices become integrated into vehicular networks, there is an added threat of theft of personal information that will need to be addressed.

Connected Vehicles will provide personal data such as location, places visited, driving speed, route, destination, and overall driving habits (such as aggressiveness, driving schedule, and so forth). This data can be used for many tasks including route optimization, emergency management and assistance, traffic congestion management, and more. A key concern with regard to Connected Vehicles is privacy especially since each car will have a transponder that may be perceived as a tracking device. The transponder for transmitting vehicular data can actually be used to track vehicles if anonymity is not adequately built into the system. The irony is that most people carry cellphones in their pockets as they drive which can be tracked for the movement of an individual just as easily. The problem is complex and requires careful examination of what data needs to be collected, at what stage will identifying information be stripped from the data, who will have access to the data, how long will the data be retained, and how will it be destroyed. This data challenge is partly technical, but primarily legal and policy-related. Research is required in the areas of policy, technology, and law to adequately address this challenge.

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The generation of mass quantities of data (which could fairly be referred to as "big data") from Connected Vehicles will necessitate the development of algorithms and software that both process and quantify these myriad events as well as provide decision assistance to many different stakeholders. Individuals, such as vehicle operators, might desire algorithms that offer early insight into possible vehicle maintenance issues that are generated from analysis of vehicles similar to theirs—commercial interests, as well, may desire such information to assist in marketing and other commerce. More simply, individual vehicle operators could find benefit in up-to-date and real-time route assistance. V2V and V2I networks could relay traffic congestion to a driver and their vehicle could suggest alternate routes using intelligent agents (such as an agent that uses your driving history to notice you're beginning your commute and makes appropriate route optimization suggestions). Groups, such as municipalities and vehicle manufacturers, would also drive demand for intelligent algorithms—a city utilizing dynamic traffic signal timing to increase the effective capacity of roads, or manufacturers to collect feedback on mechanical failures in order to make improvements. Such algorithms, agents, and applications would need to be balanced against the aforementioned data privacy implications, such as the legitimate needs of law enforcement to curtail criminal activity balanced against the privacy needs of individual drivers.

The climax of the Connected Vehicle initiative will come with the creation of driverless automated vehicles which, though decades away from becoming mainstream, continue to fuel the imagination of consumers. Tremendous research is required both in engineering and urban planning in anticipation of the emergence of such vehicles. Critical enablers for these automated vehicles are sensing, communication, and control. Initial research on sensing for vehicles was in the area of visual sensors, which are not reliable in all weather conditions. Research has moved on to radar and GPS-based sensors that are more reliable and robust. Once reliable detection has been established information needs to be communicated to other vehicles and infrastructure to ensure reciprocal actions from neighboring vehicles and infrastructure elements. As mentioned earlier, research is required in terms of ensuring adequate bandwidth, data reduction, and security of communication. Finally, control software that simulates driver behavior needs to be developed for navigating the vehicles along a route, either one specified by a driver or automatically determined based on the final destination. This not only requires research into these technologies but also infrastructure investments in cities and metropolitan areas. Creating and maintaining a ubiquitous infrastructure of Connected Vehicles is not only a technological challenge, but also a huge financial commitment.

Undoubtedly there will be a social impact of Connected Vehicles. Will collision avoidance systems lead drivers to engage in more risky behavior? Will traffic congestion increase since more people may adopt driving due to increases in driver comfort thanks to new technology? Will automated vehicles allow people to work while they are being driven? Can they sleep in their cars? What happens when the infrastructure gets damaged—will drivers lose the ability to self-drive or become incompetent at driving? There are many social challenges that need to be addressed as we move forward with the Connected Vehicle initiative; legal issues must be sorted out as well. For instance, who is liable for an accident when the driver has no control? What kind of Service Level Agreements should be created for infrastructure support (sensors, communication, etc.) to ensure safe and reliable mobility? We would need federal mandates to comply with Connected Vehicle initiatives to ensure ubiquitous availability of support for vehicles. There would be huge implications of Connected Vehicles on urban planning: Would Connected Vehicles support compact and energy efficient residences or would they simply support more urban sprawl? Would we need more parking in downtown areas or would people would just get off the vehicles and let their cars roam around until they are done shopping? Would it then follow that connected, automated vehicles institute a sea change in vehicle ownership paradigms; this is to say, if we could summon automated vehicles on a whim, would individual ownership of personal vehicles become a thing of the past? There is a marvelous opportunity to shape urban landscapes around this paradigm and it is imperative that we start research and planning on some of these issues as the technology matures and makes a universal paradigm.

International Conference on Connected Vehicles & Expo (ICCVE) was created three years ago as a forum for researchers, practitioners, and policy makers from diverse communities working on Connected Vehicles to come together and present their research, share their experiences, forecast trends and opportunities, and discuss policy, economics, and social implications. It covers a diverse range of topics including communications, networking, Internet of Things (IoT), intelligent and autonomous driving, automotive electronics, traffic optimization, spatial information systems, standards and legislation, as well as policy, economics, and social implications of Connected Vehicles. This special issue of the *IEEE Intelligent Transportation Systems Magazine* contains selected papers from ICCVE 2013 that have been extended and put through a rigorous review process. As would be expected from the broad scope of the conference, the papers in this issue are from diverse areas of communications, driver behavior adaption, vehicle localization, and wireless antenna design.

In the first paper Jiang and Du propose a two-tier Vehicular Ad Hoc Network (VANET) for buses that leverages existing roadside data collection units (RSU) and traffic control centers (TCC) as traffic infrastructures. In this architecture the communications of vehicles benefits from other buses as well as through the infrastructure elements (i.e. RSUs and TCCs). In their paper, they calibrate the benefits obtained by taking advantage of this intelligent transportation system (ITS) infrastructure. Such studies are critical to realize the potential of ITS infrastructure and understand the limitations and gaps of the existing infrastructure.

In the second paper, Corcoba-Magna and Munoz-Organero present a game that trains people in efficient driving practices to improve their fuel efficiency by providing feedback on their performance. Their goal is not only to nudge drivers to change behavior, but also to persist with the behavior. Their system uses fuzzy logic to assess the driving style from the point-of-view of the fuel consumption and rates their behavior from 0 to 1 based on their driving efficiency. They provide two types of feedback to the user. The first feedback is based on generalized rules that correlate their driving behavior to fuel efficiency of the vehicle. The second type of feedback is normative where they compare the behavior of the driver to others in similar circumstances and provide a relative performance score. They validated their experiment using 36 drivers in Spain across three different routes.

In the third paper, Rohani et al. propose a new method for improving vehicle positioning using GPS data in conjunction with vehicular network data (i.e. inter-vehicle distance in a cluster of vehicle). A Bayesian approach is used to fuse the GPS data and inter-vehicular distances and a Kalman filter to incorporate the dynamics of the vehicle. They were able to reduce localization uncertainty of vehicles through the new algorithm. They use Monte Carlo simulations to perform a sensitivity analysis (accuracy and uncertainty) for various parameters of the algorithm. Localization is key for a variety of applications including crash avoidance, signal timing, emergency assistance and route planning. This and other papers in the area will benefit engineers and designers with improving the accuracy of their systems for better results.

In the fourth paper, Phan-Huy et al. present signal beamforming schemes using the "Predictor Antenna" concept. Beam forming is done to achieve spatial selectivity of transmission and can be used at either the transmitting or receiving end. This involves combining elements in a phased array such that signals at particular angles receive constructive or destructive interference to strengthen or attenuate the signal. Their research addresses the limitations that existing beam forming techniques have for fast-moving vehicles. Their beam forming technique is able to work for vehicles moving up to speeds of 300 km/hr.

Finally, in the fifth paper, Kondyl and Sisiopik study the movements of drivers inside the vehicle, when performing specific maneuver types such as lane changing and merging to identify potentially unsafe situations. They constructed three-dimensional shapes of drivers participating in the study during lane changes and mergers. They fit a 7-point human skeletal model to the captured range data using their framework. Through the analysis of captured images they found significant differences between participants when performing similar driving maneuvers. Based on the initial pilot study they propose an elaborate experiment that to examine the differences in movements during traffic maneuvers based on demographic variables such as age, gender and experience. This research can be boot strapped for several applications related to improving driving safety in being able to predict the intentions of other drivers through this imaging technique and avoiding mishaps.

Vehicular sensing and communication is a disruptive technology that portends to change the fundamental way in which we envision transportation. There exists the potential to create a seamless ubiquitous traffic grid comprised of automated vehicles, akin to Internet traffic of packets that are routed through traffic intersections just like routers on the Internet. Traffic signals should negotiate directly with the vehicles to provide access to the intersection and attenuate or accelerate vehicle speeds to allow unfettered movement through a traffic intersection. There is significant research and development effort that is necessary in a variety of fields as discussed above. We also need to account for human factors in urban planning as well as user privacy and security centered around the concept of Connected Vehicles. Finally policies, laws, standards, and regulations need to be developed to support and fund the smart grid initiative as we move forward on this domain. The future looks bright but still requires tremendous amount of research before this field can reach its full potential! ITS