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Editorial

Special Issue: Advances in Vehicular Networks

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1. Introduction

Connected vehicles are expected to transform the way we travel through the creation of a safe, interoperable wireless communication network among road actors, infrastructures, and objects. Vehicle-to-anything (V2X) communications are, then, fundamental for next-generation active traffic safety and management applications: combined with sensor-based technologies, V2X communications will extend the awareness range of connected and automated vehicles with information received from neighboring vehicles, the infrastructure or vulnerable road users (VRUs).

International consortiums have already agreed on the basic set of applications that need to be implemented to start operating a vehicular network infrastructure at a large scale. Current access technologies, such as IEEE 802.11p (or its European version ITS-G5) and 3GPP LTE-V2X can already succeed in providing most of these so called phase 1 applications, in which vehicles exchange position, speed and other few kinematic information, but they hesitate in the advanced improvement needed to also satisfy the set of requirements foreseen by phase 2 and beyond. Phase 2, in fact, will allow various traffic participants to provide additional information, gained through various on-board sensors like cameras and radar, whereas from phase 3, vehicles will share their intentions so that each vehicle can have a glimpse into the future of other vehicles and, in phase 4, they will exchange and synchronize driving trajectories among each other.

Hence, a fully connected car will require a massive amount of computing power and super-high-speed communication systems, with latency lower than 5 ms and reliability higher than 99.9%.

This Special Issue targeted contributions we deemed relevant to addressing the demand for more reliable and ultra-low-latency vehicular applications. Seven research papers and one review paper have been selected; they range from advancements at the access layer, like the usage of the visible light spectrum to accomodate ultra-low-latency applications, to data dissemination solutions, as well as edge computing, neural-network-based techniques and the use of reconfigurable intelligent surfaces (RIS) to boost throughput and enhance coverage.

Specifically, in [1] the focus was on the improvement in the performance of vehicular networks in terms of delays and packet loss. With this in mind, the authors of [1] proposed a modified version of an ad hoc, on-demand distance vector (AODV) routing protocol to reduce the number of route requests and route reply messages, and thus to reduce the network load and overhead packets. The proposed solution can include additional information in the routing tables, such as the speed, direction and position of the surrounding vehicles. The carry and forward method is applied so that the vehicle nearest to the destination carries the information as long as the source can send the packets to those vehicles going in the same direction, thereby making the route more stable. A two-stage filtering operation is applied to remove the unwanted nodes moving in the opposite direction. Simulation results show a 1.4% reduction in packet loss, an 11% reduction in the end-to-end delay, and an increase in throughput.

A couple of works are dedicated to future scenarios in which traditional radio communications are not able to support the stricter demands on the underlying V2X connectivity technology, in terms of latency, reliability, bandwidth and capacity. Frequently sending information about all on-board sensor observations may saturate the capacity of traditional V2X communication technologies, especially in dense urban environments with a large number of equipped vehicles, as expected, as the penetration ratio of cooperative and automated vehicles (CAVs) increases. Visible light communication (VLC) is then addressed as a complementary technology to support the future demands of data-hungry cooperative sensing applications.

Paper [2] presents a characterization of a low-cost, low-latency VLC prototype for infrastructure-to-vehicle (I2V) communication. The system consists of a legacy traffic light as a transmitter and a photodetector as a receiver. The latter is equipped with low-cost Fresnel lenses as condensers to increase the optical gain in the system at the receiver. The system is capable of active decode and the relaying of information to further incoming units. The experimental characterization of amplitude and Packet Error Rate (PER) for the proposed system demonstrated the feasibility of an error-free I2V communication (corresponding to a PER lower than 10^{-5}) whithin 50 m. Furthermore, the prototype can be used for both broadcast and beaconing transmission modes. This low-cost VLC-based system could offer sub-millisecond latency in the full active decode and relay process for distances of few tens of meters, which makes it suitable for integration in Cellular-V2X (C-V2X) and 5G platforms.

In [3], VLC is jointly used with 5G to provide real-time information to vehicles. This paper presents a field-test that integrates 5G communication capabilities with VLCs to test the end-to-end latency that can be offered by this integrated communication network in a vehicular scenario.

In [4], the concept of information hovering for data dissemination over a mobile set of peers is addressed to make the given information available to all vehicles within a confined geographical area in a specific time period. The paper proposes a strategy based on epidemic routing in the hovering area, and probabilistic flooding outside it to avoid some vehicles never receiving the content dedicated to them due to eventual partitions and disconnected areas created by low traffic density. To this aim, vehicles outside the hovering area serve as bridges towards partitions, leading to high reachability. The work highlights the adaptive feature of the protocol, where the rebroadcast probability in partitions is adaptively regulated based on estimates of the density of vehicles in the hovering area. The performance of the proposed scheme is evaluated in realistic conditions, using a section of the road network in cities of Washington as the reference model in all simulations.

The important topic of vulnerable road users (VRUs) is faced in [5], where vehicle-to-pedestrian (V2P) communications are considered to support road safety by enabling all road users to exchange information. This paper presents an architectural design to support V2P communications and to provide interfaces for vehicle and pedestrian in safety-oriented applications; in addition, Reference [5] proposes a couple of implementable applications for pedestrian safety that could be implemented in tablets and smartphones. The proposed solution is based on the integration of Wi-Fi and IEEE 802.11p in the on-board unit (OBU) of vehicles so that the vehicle can communicate via Wi-Fi with the pedestrian, sending reliable and efficient warnings, whereas IEEE 802.11p is used for V2V communications. Interesting discussions on actual hardware and software solutions are reported, indicating the potentialities and limits of actual wireless technologies in vehicles' and users' smartphones and discussing potential solutions that could be made available when the pedestrian device will be equipped with the most suitable wireless access technologies for vehicular communication scenarios, such as C-V2X and 5G.

Since the connected vehicles can provide a large variety of services, they could be based on different wireless access technologies and they need different network requirements, such as low latency, high computational capacity, and high reliability. In [6], the authors proposes an integer linear program (ILP) to solve the joint deployment problem of baseband processing and edge computing with reliability against single-node failure in a cloud radio access network (C-RAN) to minimize the nodes in which processing capabilities must be installed while ensuring that latency and optical link (i.e., maximum wavelengths over fibers) constraints are not violated. To overcome the computational complexity of classical optimization approaches, a hybrid based on both heuristic and ILP deployment strategy is also proposed. The algorithm performs a first phase, in which the initial set of nodes as candidates for host baseband and edge computing functions is reduced and a suboptimal solution is provided. Then, a second phase is executed for optimization purposes. The latter approach is shown to provide results close the optimal ones while considerably reducing computational time.

The work in [7], instead, investigates the suitability of convolutional neural networks (CNN) for the diagnosis of defective automotive dampers. In fact, chassis system components such as dampers have a significant impact on vehicle stability, driving safety, and driving comfort. Currently, in addition to the driver's perception, there is only periodic human inspection for monitoring the vehicle's chassis system state. However, this is error-prone, expensive and implies periods of unmonitored driving between inspections and cannot be applied in future self-driving cars. Therefore, an automated monitoring and diagnosing system is of high importance. Authors' experiments were conducted with different parameters regarding the size of the receptive field, the size of the pooling layer and the network depth of the CNN architecture, and the resulting kernel weights of the trained networks were analyzed. To ensure a broad applicability of the generated diagnosis system, only signals of a classic electronic stability control (ESC) system, such as wheel speeds, longitudinal and lateral vehicle acceleration, and yaw rate were used. A structured analysis of data pre-processing and CNN configuration parameters were investigated in terms of the defect detection result. The results show that simple fast Fourier transformation (FFT) pre-processing and configuration parameters resulting in small networks are sufficient for a high defect detection rate.

Finally, in the review paper [8], the unprecedent importance of a smart environment besides connected and automated vehicles is addressed. A smart environment could drastically enhance the performance of wireless access technologies and connected vehicles. Hence, as more and more connected and autonomous vehicles hit the road, we need to smarten up the streets on which we travel, for example, by coating the environment with reconfigurable meta-surfaces, able to customize the radio wave propagation and opportunistically reach the target. Meta-surfaces are thin electromagnetic meta-materials, typically deeply sub-wavelength in thickness and electrically large in transverse size. They are composed of sub-wavelength scattering particles that can revise the Snell's law redirecting the radio waves in the desired direction and can achieve this run time, changing the redirection of the waves over time. Hence, the major difference between a surface and a meta-surface is the capability of the latter of shaping the radio waves according to the generalized Snell's laws: for example, the angles of incidence and reflection of the radio waves are not necessarily the same. Beyond the meta-surface, what is really challenging and stimulating is the use of a reconfigurable meta-surface, where the scattering particles are not fixed from the manufacturing phase, but can be modified depending on the stimuli that the meta-surface receives from the external world. The work in [8] describes the main characteristics of meta-surfaces and highlights the potential uses of reconfigurable meta-surfaces, especially when adopted in vehicular environments, focusing specifically on cooperative driving and vulnerable road user (VRU) detection. An analytical model (validated by simulation) is also presented to demonstrate the improvement that a reconfigurable meta-surface can provide in reducing the collision probability when random access to the medium is adopted for vehicle-to-vehicle (V2V) communications.

It is hoped the readers will appreciate this Special Issue enhancing their knowledge in the area of enabling technologies for connected and automated vehicles and helping them advance their on-going research and innovation activities.

Conflicts of Interest: The authors declare no conflict of interest.

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