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Editorial

Cooperative, Connected and Automated Mobility (CCAM): Technologies and Applications

Joaquim Ferreira

Instituto de Telecomunicações/ESTGA, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; jjcf@ua.pt

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1. Introduction

The advent of cooperative connected and automated mobility (CCAM) has the potential to fundamentally change the mobility paradigm towards mobility as a service, contributing to more safe, efficient and comfortable transportation systems. To materialize this visionary scenario, with a great societal impact, different aspects are involved, ranging from regulatory issues, standardization, certification and technological issues.

Current vehicles can already be considered to be connected devices, as many recent models are connected to external services, for infotainment, security, comfort and maintenance purposes. Furthermore, direct interaction among vehicles, pedestrians and the road infrastructure, using various radio technologies, is expected, in the short term, using consolidated and field-proven technologies. In parallel, the massive effort being made by many stakeholders towards automated driving, is mostly centered in the vehicles' sensors, as no automated actions are currently made based on data received from other vehicles or from the road infrastructure. However, it is commonly accepted that inter-vehicle cooperation will significantly enhance the overall traffic performance, safety and comfort. Vehicular communication will also foster the integration of automated vehicles within the intelligent transportation ecosystems, with automated vehicles communicating and cooperating with legacy vehicles, trams, bicycles, etc.

Vehicular communications, automated driving and cooperating transportation systems are increasingly being considered not only as complementary technologies, but also as the foundations of forthcoming visionary CCAM applications. To this end, regulatory entities, automotive OEMs, road operators, telecom operators and other stakeholders are converging to deploy large-scale infrastructures and field trials of cooperative intelligent transport systems to pave the way to cooperative, connected and automated vehicles.

2. The Present Issue

This Special Issue features seven articles highlighting recent advances of the state of the art in different technologies for cooperative, connected and automated mobility. The contents of these papers are introduced and summarised next.

Two papers address vehicular platooning, a key application of automated driving. The paper by Aslam et al. [1] presents empirical models relating the number of radio frequency (RF) neighbors that a platoon member, in a highway platoon-only scenario, observes, with relevant network performance metrics. The platoon performance largely depends on the quality of the communication channel, which in turn is highly influenced by the adopted medium access control protocol (MAC). Currently, VANETs use the IEEE 802.11p MAC, which follows a carrier sense multiple access with collision avoidance (CSMA/CA) policy, that is prone to collisions and degrades significantly with network load. This paper considers CSMA/CA, native IEEE 802.11p, and two TDMA-based overlay protocols, i.e., deployed over CSMA/CA, namely PLEXE-slotted and RA-TDMAp, to carry out extensive simulations with varying platoon sizes, number of occupied lanes and transmit power to deduce empirical models that provide estimates of average number of collisions per second and average busy time ratio. Simulation results show that these estimates can be obtained from observing the number of RF neighbors, i.e., number of distinct sources of the packets received by each vehicle per time unit. These estimates can enhance the online adaptation of distributed applications, particularly platooning control, to varying conditions of the communication channel.

The other paper on platooning, from Liu et al. [2] presents a state predictor based control strategy for heterogeneous vehicular platoon connected by non-ideal wireless communication. From the theoretical analysis and simulation results, it was concluded that both information delay and topological uncertainty caused by non-ideal wireless communication are critical to the stability and tracking performances of platoon, which need to be dealt with when synthesizing a platoon control system. Furthermore, when considering the information delay, besides the minimum topological eigenvalue the maximum one also affects the closed loop performance of platoon. Comparatively, the influence of minimum one can be ignored if only stability is taken into account. The proposed state predictor based control strategy can compensate for the information delay and the numerical approach based on LMI can find the required state feedback controller ensuring robust performance of platoon.

The paper from Zheng et al. [3] proposes a dynamic multi-task scheduling prototype to improve the limited resource utilization in the vehicular networks (VNET) assisted by mobile edge computing (MEC). To avoid conflicts between tasks when vehicles move, multi-task scheduling was regarded as a multi-objective optimization problem, with the goal to find the Pareto optimal solution. For this purpose, a Frank–Wolfe-based MGDA optimization algorithm was proposed and extended to the high-dimensional space. This paper concluded that Pareto optimal solution can be computed by an upper bound optimization.

The work presented in the paper from Franco et al. [4], addresses critical train communications, an increasingly important aspect of CCAM both for the automated trains and for the cooperation between trams and other vehicles. The paper presents an architecture based in 5G, SDN and on MPTCP to provide path diversity and end-to-end redundancy in order to contribute to a technology-independent and resilient communication service. In this architecture, SDN is a key enabler for addressing network flexibility and adaptability, due to its centralized control and its ability to deal with failures at runtime. Results indicate that the combination of MPTCP and SDN improves the train to ground communication performance indicators, compared to a legacy approach. MPTCP offers end-to-end redundancy by the aggregation of multiple access technologies, and SDN introduces path diversity to offer a resilient and reliable communication. Simulation results indicate that, when compared to a legacy communication architecture, the approach presented in this paper, demonstrate a clear improvement in the failover response time, while maintaining and even improving the uplink and downlink overall data rates.

The paper from Liu and Jaekel [5] presents a comprehensive survey of congestion control approaches for VANETs. Several relevant parameters and performance metrics, that can be used to evaluate these approaches, were identified and each approach was analyzed based a number of factors such as the type of traffic, whether it is proactive or reactive, and the mechanism for controlling congestion. It was concluded that there are still many challenges and open research problems for congestion control in V2V safety communications, namely joint power/rate control, improved awareness control, relative fairness and standardization.

Two review papers provide a systematic review of fault tolerance techniques for wireless vehicular networks [6] and an overview of the status of the policies and practices of cooperative driving in the European Union [7]. Fault tolerance techniques for wireless vehicular networks [6] are of utmost importance for safety-critical CCAM applications, such as cooperative self-driving cars and automated mobility in general. The paper by Almeida et al. [6] presents a systematic literature review, on this issue, of publications in journals and conferences proceedings, available through a set of different search databases. For that purpose, The PRISMA systematic method was adopted in order to identify the relevant papers for this survey. A comparison of the core features among the different solutions is presented, together with a brief discussion regarding the main drawbacks of the existing solutions, as well as the necessary steps to provide an integrated fault-tolerant approach to the future vehicular communications systems. It was observed an increasing trend in the recent years, with more protocols, mechanisms and architectures being proposed in order to enhance the dependability attributes of wireless vehicular networks. Nevertheless, there is still a shortage of strategies to completely fulfill the operation of dependable vehicular networks.

The paper by Botte et al. [7], mostly centered in roadside deployment activities, analyzes the policies and practices of cooperative driving in the European Union, aiming to shed a light on the current state of testing and deployment activities in the field at the start of 2019. This study is particularly timely given that the year 2019 was identified as the starting date for the deployment of mature services, and because the European Union legislation is paying great attention to the matter. An important conclusion of this paper is that the proliferation of autonomous vehicles, will significantly increase both the traveled distances and the number of trips. This will negatively impact the potential benefits of autonomous driving in terms of sustainability and congestion reduction.

3. Conclusions and Prospective Future Research Directions

This Special Issue has partially addressed some relevant CCAM-related technologies. There are, however, many more fundamental technologies for CCAM that were not considered here as, for example, cooperative perception, 5G and ultra-reliable low-latency communications, safety and security, advanced sensors, distributed control algorithms, machine learning, etc.

Over the last few years, both automotive OEMs and academia have dedicated a massive effort developing technologies for CCAM. Industry focus on CCAM has been mostly centered on automated driving, with some effort devoted to connectivity and very limited action towards cooperation between vehicles. Although there are still many open issues in the vehicle automation field, the automated cooperation between vehicles, e.g., for cooperative maneuvering, has the potential to dramatically increase the overall traffic efficiency and safety. Vehicle cooperation requires ultra-reliable low-latency communications, both short-range for, e.g., maneuver negotiation and long-range for, e.g., traffic management. Communication technologies supporting these requirements are already available, but the main impairments for automated inter-vehicle cooperation are trust and liability. In this context, there is still a wide range of prospective future research directions, in the various domains of CCAM: automated driving, vehicular networks and inter-vehicle cooperation.

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