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Distributed learning strategies for the management of traffic of connected and autonomous vehicles

Keywords: Simulation; Multi-agent Systems; Machine Learning; Traffic Engineering; Autonomous Vehicles;

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Description of the Hosting Institution

The 'Université de Bourgogne Franche-Comté (UBFC) is a community of universities and high schools with around 56,000 students, located at the Center-East of France. It is composed of 22 geographical sites. UBFC was created April 1st, 2015. The founding members are: Burgundy University (UB) , Franche-Comté University (UFC), Université de Technologie de Belfort-Montbéliard (UTBM), High National School of Mecanics and Microtecnics (ENSMM), AgroSup Dijon, Burgundy School of Business (BSB, formerly ESC Dijon).

The 'Université de Technologie de Belfort-Montbéliard' (UTBM) is a public higher education and research institution located in the towns of Belfort, Sévenans and Montbéliard (Franche-Comté, France). The university has 2,555 students for the academic year 2011-2012. UTBM comes from the merging of the National School of Engineers of Belfort (ENIBe) created in 1962, and the department of the University of Technology of Compiègne established in 1985 in Sevenans, becoming "Sévenans Polytechnic Institute" (IPSE) in 1991. UTBM was founded in 1994. It belongs, like the University of Technology of Compiègne, the University of Technology of Troyes, and the University of Technology of Shanghaï, to the Network of the Technology Universities. UTBM is a member of the National Council of the French High Schools, the Conference of Directors of French Engineering Schools, the Conference of University Presidents, founder of the Bourgogne Franche-Comté Research and 2 Education Pole, founding member of the ARC-Europe Project, and member of UT Group. UTBM is authorized by the Ministry of Higher Education and Research to issue engineering diplomas in the following domains: automatic, industrial electronics, IT, mechanical, production systems, mechanical design and ergonomics. UTBM is developing research activities in cohesion with the industrial environment of the north Franche-Comté: Land transport and energy. Seven laboratories research is organized around UTBM.

The **CIAD laboratory** (Laboratoire Connaissance et Intelligence Artificielle Distribuées, http://www.ciad-lab.fr) is a multidisciplinary research laboratory that is hosted by UTBM and UB. In 2019, Researchers from UTBM has created the CIAD staff. These Researchers are mostly members of the multiagent research group whose head is Prof. Dr. S. Galland. The members of the CIAD includes 6 full professors, 4 professors, 5 associate professors, 12 contract researchers, 2 research engineers, 2 post-doc and 27 PhD students. Within the CIAD laboratory, the multiagent team investigates the field of Multi-Agent Systems (MAS).

The core activity of CIAD in related with this PhD subject is concerned with computer languages, methods, and tools, and aims at defining suitable abstractions, methodologies either formal or semi-formal and tools for engineering multiagent software based on organizational and behavioral theories and constitute a basic building block for the other research projects of the team. The scientific work of the team is organized around three fundamental axes: Agent-Oriented Software Engineering and Formal models, Multiagent-based Simulation, and Agent's architectures. Our main application areas cover Intelligent Transport Systems (ITS), traffic and pedestrian's simulation in virtual environments. Currently, the two following areas draw the attention of the team: Simulation in virtual environments, and the Modelling, simulation and control of multimodal traffic.

The PhD candidate will be hosted on the **campus of UTBM** located in the human-sized city of Belfort.

Scientific Context and Problems

Autonomous cars are vehicles equipped with sensors, actuators and computer software, enabling them to drive according to their perceived environment (road, vehicles, pedestrians, etc.) [4]. These new vehicles, whose time-to-market is estimated to a few more years, will improve the road users' safety and allow new forms of mobility.

These vehicles will also be equipped with communication units allowing them to receive information from the other vehicles and the infrastructure, and to emit information toward their environment. By using the wireless communication, these Connected and Autonomous Vehicles (CAV) will introduce new possibilities for traffic management. Several researches have shown the potential benefits of CAVs on the traffic:

- at intersections, by removing the need of traffic lights while improving the traffic efficiency [1], or by signaling their intent to pedestrians to ensure safety and efficiency [5]
- on the highway, by allowing cooperative merging [2]
- on the whole road network, by preventing the risks of deadlocks [3]

The research work on the possibilities of these CAVs is still on-going and new possibilities are continuously being discovered to improve the traffic. Indeed, thanks to the recent works, it is expected that CAVs will improve safety, reduce congestion, and improve the energy consumption.

The current thesis subject aims to continue the on-going work on traffic optimization of CAVs with a new approach.

A key issue of the current solutions is the difficulty to perform online optimization of the traffic when the activity on the road is constantly changing and the evolution of the traffic at the vehicle level is hard to predict.

The recent advances of machine learning (ML) and especially reinforcement learning could be a solution to this problem. Nowadays, in the transportation domain, ML is commonly restricted to the computation of phases of adaptive traffic lights, yet the new possibilities of control of vehicles (thanks to CAV) allow a more fine-grained control of the traffic. ML could be used to define new strategies for traffic management at different levels (vehicle, intersection, network) able to dynamically adapt to the ever-changing environment.

Before the application of these new techniques for the control of city traffic, several generic research questions must be answered, including:

- **How can we design a model in charge of controlling the vehicular traffic in a city?**
- **What gains (travel-time, energy consumption, etc.) can be expected by totally delegating the traffic control to an AI?**

Recently, deep reinforcement learning is one of the most widely used methods to successfully control vehicles. It allows accomplishing complex driving tasks, by learning from real situations and also from simulated situations with fuzzing techniques to consider extreme cases. Nevertheless, this technique is currently used only to control a single vehicle. Many situations in the field of transportation require interactions between connected and autonomous vehicles (CAV) to leverage the traffic congestion. These interactions can be either conflicting as in the case of intersection or collaborative as when CAVs should find a consensus to invite the pedestrian to cross the road. In both cases, the CAV's movements must be synchronized to accomplish their tasks safely. Multi-agent deep reinforcement should help but is still an open research subject that needs to be thoroughly addressed. This thesis will focus on conflicting situations.

The thesis work focuses on cooperative intersection management of connected and autonomous CAVs. This subject is in the topicality of this decade. On the one hand, the cooperative intersection management has a great potential to increase the road network capacity and to save energy in the future urban transportation. On the other hand, it can be implemented in industrial sites to enhance the production efficiency in a very near future. Our first studies define optimal trajectory control to gain times between two conflicting CAVs and a very efficient negotiation between CAVs to form a sequence (which CAV goes first, which one is the second and so on) that increase the throughput. However, the system is dynamic, firstly, because of the movement of CAVs. Secondly, new CAVs arrive to the intersection system and modify the already found optimal trajectory. The thesis subject aims to find a balance between both decisions (trajectory and sequence) to cope with the uncertainty of the traffic at intersections.

First, deep reinforcement learning, and second multi-agent deep reinforcement learning will be used to address this issue. The thesis will then study first a single agent control that interacts with a random new VAC arrival. The research study will gradually integrate several CAVs in the intersection. The use of distributed metaheuristics and comparison is appreciated.

The PhD student will benefit from the experience of a pioneer team in the subject. The team exhibited the first real cooperative intersection management of three CAVs in ITS World Congress in 2015. It also wins the second place among 374 participants in the DAI2020 SMARTS Competition of Autonomous Driving organized by Huawei. She/he benefits from a well-equipped laboratory with platforms that include a microscopic traffic simulator, a high computation capability, small robots and three real vehicles open to be controlled.

Goals of the PhD works

This PhD subject aims at designing an artificial intelligence model to efficiently manage the traffic in a city.

Depending on the open research questions at the time of the start of the PhD thesis, and the background of the PhD candidate, the research questions that may be tackled by the PhD candidate are:

- **Which machine learning approach is the most promising to address the problem of traffic management?**
- **Which structure of neural network could be used to model the traffic management policy?**
- **How can an ML-based traffic management solution be deployed in a realistic environment?**
- **How deep reinforcement learning traffic management compares with classical solutions?**

The scientific fields that are supposed to be explored by the PhD student are the machine learning, the traffic management, and the connected and autonomous vehicles (cyber-physical systems).

Expected Background for the Candidates

This section lists the expected background for the candidates:

- **Computer programming with either Python, Java, or C# (mandatory knowledge)**
- Machine Learning (especially deep reinforcement learning)
- Artificial Intelligence and Multiagent Systems

Expected Working Plan

Year 1 (Months 1-12)

- Do a Systematic Literature Review (SLR) according to the international standards in order to highlight the key research questions in the field of this PhD thesis
- Selection of one or two research questions from the SLR to be handled by the PhD candidate.
- Writing and publication of one paper into an international journal of Rank Q1 or Q2 that explains the SLR;

Year 2 (Months 13-24)

- Design of ML models for the control and optimization of the vehicular traffic in a city
- Writing and publication of papers into international conferences with ready committee.
- Writing and publication of a paper into an international journals of Rank Q1 or Q2 that explains the proposed models;

Year 3 (Months 25-36)

- Implementation and experimentation of the models in a simulated environment
- Writing and publication of papers into an international conference with ready committee.
- Writing and publication of a paper into an international journals of Rank Q1 or Q2 that explains the experiments and the results.
- Preparation of the final PhD document;

Year 4 (Months 37-42)

- Preparation of the final PhD document
- Official oral defense

Bibliography

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