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NETWORK OF AUTOMATED VEHICLES: THE AUTONET2030 VISION

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Abstract

AutoNet2030 – Co-operative Systems in Support of Networked Automated Driving by 2030 – is a European project connecting two domains of intensive research: cooperative systems for Intelligent Transportation Systems and Automated Driving. Given the latest developments in the standardization of vehicular communications, vehicles will soon be wirelessly connected, enabling cooperation among them and with the infrastructure. At the same time, some vehicles will offer very advanced driving assistance systems, ranging from Cooperative Adaptive Cruise Control (C-ACC) to full automation. The research issues addressed in AutoNet2030 are as follows: how can all these vehicles with different capabilities most efficiently cooperate to increase safety and fluidity of the traffic system? What kind of information should be exchanged? Which organization (e.g. centralized or distributed) is the

best? The purpose of this paper is to introduce the vision and concepts underlying the AutoNet2030 project and the direction of this ongoing research work.

Key words

Intelligent Transportation Systems (ITS), Cooperative ITS, Automated driving, Communication, Network, AutoNet2030, platooning, formation

AutoNet 2030 vision

Cooperative ITS

Cooperative Intelligent Transportation Systems (ITS) require good communication channels and this is about to be deployed: bandwidth is there and hardware is being industrialized. They require also a common language to exchange data; a release 1 has already been completed for Europe and the US by standard development organizations. Moreover, vehicle manufacturers are ready to deploy the solution in their vehicles; therefore, it is clear we will see some cooperative ITS in real operation already during 2015.

A major goal in large scale cooperative systems is the right level of information sharing between agents: it must be enough to ensure cooperation (e.g., cooperative maneuvering) but not too much to avoid the congestion of communication channels. Therefore, messages will not be the same for local purposes (e.g. safety) and more global purposes (e.g. traffic management) but the trade-off between local and global is difficult.

Moreover, since on-board perception of single vehicles will probably not be sufficient to guarantee its driving safety (e.g. buildings may prevent the detection of incoming traffic at an intersection), cooperative perception is a must. Once cooperative vehicles and infrastructure servers are able to perceive more globally the traffic, they will use this information to enhance their abilities (e.g., traffic management for infrastructure servers, cooperative maneuvering for vehicles).

For both tasks, maneuvering and perception, inter-vehicle cooperation brings a clear advantage. However, cooperative decision making, and cooperative driving in particular, present several challenges that will be analyzed next.

Our long-term vision of cooperative ITS clearly leads to the concept of advanced driving assistance systems in which the driver no longer needs to retain full control of the vehicle. Next, we investigate this concept, known as cooperative automated driving, in more detail.

Automated Driving

Up to date, automated driving research has been focusing on sensor-based vehicle automation [7]. Most current automated vehicles are therefore performing *autonomous* driving, meaning every driving decision is taken within the vehicle. While sensor-based systems developed in past research projects such as HAVE-IT [1], SARTRE [2] and InteractIVe [3] have

demonstrated automated driving in platooning scenarios and highly automated driver assistance, fully automated driving still requires further research and development. A significant effort needs to be undertaken to achieve fully automated driving systems with a superior safety performance than a human driver, despite the inferior general cognitive capabilities of computers with respect to humans. This achievement is a prerequisite to create the public acceptance and trust needed for the deployment of automated vehicles.

Cooperation and Automated Driving in AutoNet2030

Co-operative systems have just recently started to be explored in the context of automated driving, mainly for the purpose of exchanging position and sensor data, i.e., cooperative perception. The next step in the exploitation of co-operative systems is the maneuvering negotiation. Cooperative maneuvering opens up the possibility of involving also manually-driven cars with installed cooperative system technology into such co-operation, advising drivers when to initiate a lane-change or when to make space for a merging vehicle. However, it takes careful system-level design to extend cooperative maneuvering control from handling just well-defined groups, such as platoons, to also manage generic traffic flows. It is the scope of AutoNet2030 to advance previous research results regarding the automation of vehicle platoons, extending controlled maneuvering to generic traffic flows. Therefore, AutoNet2030 considers more *networked automated driving* than *autonomous* driving.

With the growth of urban agglomerations, drivers more frequently need to perform lane changes in congested traffic situations or at unfamiliar locations, which is a source of stress and potential traffic incidents. As urban centers grow, guided and/or automated maneuvering becomes ever more important for traffic safety and efficiency reasons. Furthermore, as automated vehicles become deployed in significant numbers, the interactions among them must be guided by a well-defined and interoperable set of rules.

The main objective of the AutoNet2030 project is therefore to research and validate procedures and algorithms for interaction control among co-operative vehicles, including both automated and manually-driven vehicles with cooperation capabilities. The intention is to define a maneuvering control approach that is very scalable with respect to the number of equipped vehicles, is capable of dealing gracefully with failures, and supports both early and late deployment stages of fully automated vehicles.

The vision of deployment of technologies in AutoNet2030 is depicted in the illustration below.

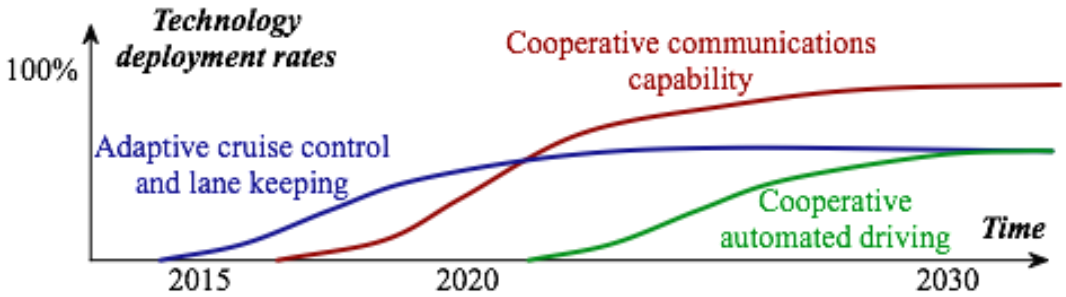

Figure 1: AutoNet2030 vision for cooperative automated driving [4]

A hybrid coordination approach

Imagine that in the future most vehicles will be networked with other vehicles and possibly with some road infrastructural units. This represents a huge system, sharing information in real time both locally (short distance, e.g., for safety) as well as globally (with servers, e.g., for efficient navigation). On the one hand, such very large interconnected system cannot be managed in a centralized way simply because of scalability reasons. On the other hand, while decentralized systems show several inherent advantages over centralized architectures, including fault tolerance, reliability, and scalability, they typically provide less optimal performances. Therefore, one of the key challenges AutoNet2030 must address is that of finding an appropriate trade-off between centralization and decentralization of the management of a traffic system. In particular, the main question is how to design architectures that provide the necessary information flow at each level: (i) locally, it should support dynamic and very accurate data exchange to ensure safe and smooth maneuverings of the vehicles; (ii) globally, it should support the sharing of an aggregated performance of the system in order to coordinate the behavior resulting from local driving patterns. A hybrid coordination approach could therefore provide the benefits of both distributed and centralized architectures. For example, the shock-waves problem in nowadays traffic jams caused by the flow of "egoistic" automated vehicles could be very well addressed by such systems.

There is currently no consensus for these structures and their role. So we will introduce the concepts that have emerged in AutoNet2030 so that they can be challenged and enhanced in later work. Our contribution is to organize a framework so that the algorithms that will be later developed and evaluated in AutoNet2030 could be compared with other works.

Terms and Definitions

First, we have to define the boundary of our system: *AutoNet* refers to a system which consists of all cooperative vehicles and infrastructure. The main objectives for *AutoNet* are to improve road traffic flow, improve journey time estimation accuracy, traffic safety, reduce CO2 emissions and enhance driving comfort by means of communication and cooperation. The objectives are achieved by wireless information exchange between *cooperative vehicles* through what we call *local cooperative areas*. *Local cooperative areas* keep track of legacy vehicles, perform incident detection, advice on appropriate speed to achieve a better road traffic flow, support lane changes and merging. Several *local cooperative areas* can create a

global cooperative area to disseminate information on a larger geographical area (example of information could be adverse weather conditions on a specific stretch of road, road works, sudden congestion).

A *local cooperative area* can be either *static* or *dynamic*. The *static cooperative area* is a function residing in infrastructure, e.g., roadside units, which is facilitating cooperation between cooperative vehicles in urban areas and at strategic places such as a highway entrances. Within the *static control area*, maneuvering information is shared. The static control area is *not moving*. The *dynamic cooperative area* is facilitating cooperation between cooperative vehicles sharing similar traffic objectives, i.e., typically a group of vehicles moving on the same highway section in the same direction in short vicinity (e.g., 1-2 km). Within the *dynamic cooperative area* maneuvering information is shared. The *dynamic cooperative area* is moving while the group of vehicles is moving.

This notion of *local cooperative area* is new and central in AutoNet2030 for cooperation. But there may be even stronger cooperation, e.g. in *platoons*. A *platoon* is defined as a group of two or more *automated cooperative vehicles* in line, maintaining a close distance, typically of 0.25 seconds[1] to reduce fuel consumption by air drag. The *platoon* interacts with the *local cooperative area* as one entity. A *platoon* has a *platoon leader* that ensures coordination within the *platoon* and interactions between the *platoon* and the *local cooperative area*. There can be several platoons in a *local cooperative area*. AutoNet2030 also introduced an extension of the idea of strong interaction underlying the *platoon*: the *convoy*. A *convoy* is a group of three or more *cooperative vehicles* maintaining a formation (typically their defined by specific inter-vehicle distances and speed alignment) using cooperative adaptive cruise control (C-ACC), with a distance greater than 0.5 s. A *convoy* does not have a *leader*, i.e., they self-organize. There can be several *convoys* in one *local cooperative area*.

We introduced the concept of *master* for the sake of partially centralizing the cooperation. A *master* is an entity in a *local cooperative area* in charge of the interactions between its *local cooperative area* and other areas and entities (e.g., between a *platoon* and a *local cooperative area*), and also coordinating the sharing of information and the cooperative maneuvering within its *local cooperative area*.

The main concepts have now been introduced. For the sake of completeness we defined what kinds of vehicles are involved in the traffic system considered by AutoNet2030. Vehicles are classified by their way of interacting regardless of their other characteristics (e.g., their weights).

The main mode is the *cooperative mode*, where the vehicle can communicate with other vehicles and the roadside infrastructure using ITS-G5 and its associated European ITS protocols such as GeoNetworking, CAM, and DENM (see the ETSI documents [5],[8]). A *cooperative vehicle* may support LTE communication. Moreover the vehicle is able to sense its surrounding, share its perception with other *cooperative vehicles* and exchange commands for automated maneuvering. In *cooperative mode*, the vehicles advice the driver with

[1] Here, the distance is normalized to the vehicle speed and therefore given in units of time and not in meters. A normalized distance of 0.25 seconds corresponds to a distance of about 7 meters at a speed of 100km/h.

appropriate actions depending on road traffic situation. The *cooperative automated mode* extends the *cooperative mode*, by adding automated control of the vehicle, i.e., the vehicle controls lateral and longitudinal movements automatically based on in-vehicle sensors and received information from other *cooperative vehicles*. This mode may be activated by pressing an "auto-pilot button".

Then vehicles are simply divided into 4 classes. A *cooperative vehicle* is a vehicle with a *cooperative mode*. All vehicles considered in AutoNet2030 support the *cooperative mode*. A *cooperative vehicle* is manually driven, i.e., it guides the driver. A *Cooperative automated vehicle* is a vehicle supporting *cooperative automated mode*. The *cooperative autonomous vehicles* are a subset of *cooperative vehicles*, with the addition of automated driving. All *automated cooperative vehicles* are *cooperative vehicles* and all *automated cooperative vehicles* can be driven manually and thereby act as a *cooperative vehicle.* A *legacy vehicle* is a vehicle with no *cooperative mode*. It has no cooperative driving capabilities and it is not able to participate in *AutoNet*. Note that, in AutoNet2030, automated vehicles with no *cooperative mode* are treated as legacy vehicles. Finally there is the *manually driven vehicle* that may be a *legacy vehicle*, a *cooperative vehicle* or a *cooperative automated vehicle* driven manually by choice.

Urban and motorway illustrations

These concepts are illustrated below in order to give them a more concrete signification. The drawing also shows how the various entities interact. There is obviously a tremendous combinatory of relationship and one challenge of AutoNet2030 is to produce algorithms and proof of consistency in any configuration.

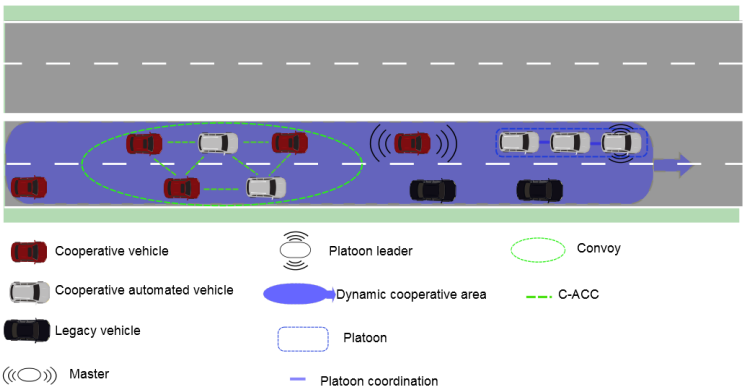

Figure 2. Motorway illustration of a *local cooperative area*. Since vehicles are moving at a very similar speed, there is a clear benefit to have a moving area, i.e. a *dynamic cooperative area*. Within this blue area, there are vehicles and other structures, like a *platoon* and a *convoy*.

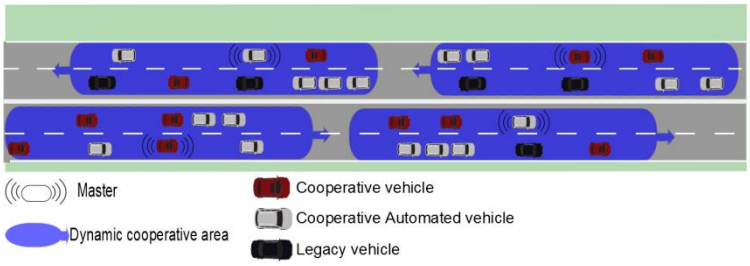

Figure 3. Blue areas representing *local cooperative areas* interact within a *global cooperative area*.

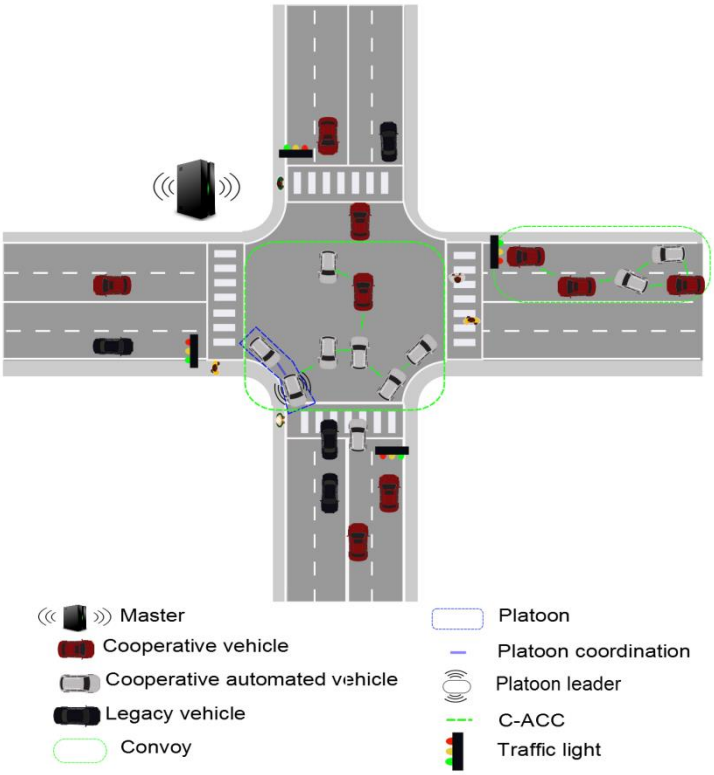

Figure 4. Urban case: the whole intersection is a *local cooperative area*. Here the infrastructure organizes the cooperation so that we have a *static cooperative area.* The *convoy* structure can be used to synchronize vehicles (or *platoons*) passing by the intersection.

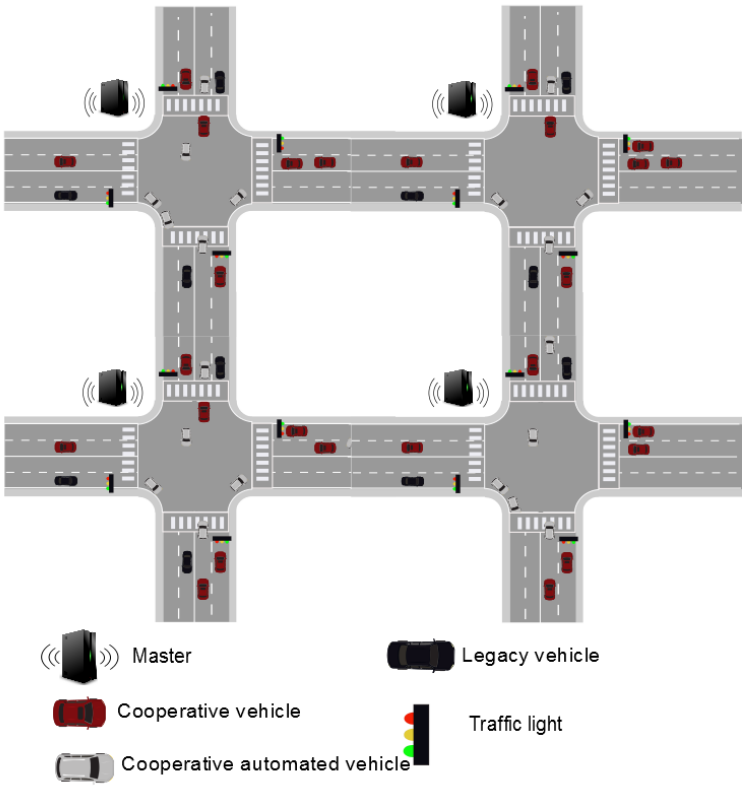

Figure 5. As in the motorway case, traffic management takes benefit of a grouping of *local cooperative areas* into a *global cooperative area* in order to build a more comprehensive scheme.

Perspectives

This paper introduces a framework to deal with traffic management, both at a microscopic and macroscopic scale, for cooperative automated and manually-driven vehicles. This framework was discussed internally and externally to the AutoNet2030 consortium in order to propose a working framework consistent with current cooperative standards published by CEN, ETSI, IEEE and ISO [8],[9]…) that can be refined in successive steps. The defined terms and definitions are still not frozen but offer researchers and engineers from different fields a tool to discuss the effect of the large-scale introduction of cooperative and automated vehicles in the near future.

In order to fulfill our vision of a network of automated and manually-driven vehicles which coordinate smoothly, ensuring both safe local cooperation and global traffic efficiency, there are still several challenges to overcome. The first challenge considered in AutoNet2030 is the cooperative perception, i.e., the design of algorithms for information sharing among cooperative vehicles. For instance, the precise definition of what information should be shared at each level – e.g. Local Dynamic Map updates locally and macro-scale traffic

indicators globally – is currently under research. Local cooperative perception has been an active research topic in the past years while multi-scale cooperative perception is a more innovative concept (though already introduced by the COM2REACT European project [6]).

Cooperative maneuvering is the second big research challenge tackled in AutoNet2030. Very linked to cooperative perception (decision making processes depend on the system state estimation), local cooperative maneuvering deals with a combination of in-vehicle and out-of-the-vehicle decision making. There is a clear challenge for algorithms to maintain as much as possible critical decision making within the vehicle while ensuring well-coordinated maneuvers: this is again another perspective of the centralized-distributed dilemma.

In summary, AutoNet2030 offers a new framework where several research areas – communication, perception, distributed control… – converge to define what suitable cooperative automated maneuvers are. Furthermore, the project aims at contributing to new sets of standards and messages to be exchanged so that tomorrow's vehicles cooperate effectively by talking a common language and following common rules

ACKNOWLEDGEMENTS

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REFERENCES

[1] HAVE-IT Project, "Highly Automated Vehicles for Intelligent Transport", URL: http://haveit-eu.org

[2] SARTRE Project, "Safe Road Trains for the Environment", URL: http://www.sartre-project.eu

[3] InteractIVe Project, "Accident Avoidance by Active Intervention for Intelligent Vehicles", URL: http://interactive-ip.eu

[4] AutoNet2030 Project, "Co-operative Systems in Support of Networked Automated Driving by 2030", URL http://www.autonet2030.eu

[5] ETSI, European Telecommunications Standards Institute, URL http://www.etsi.org

[6] COM2REACT Project, www.com2react-project.org

[7] A. Geiger, P. Lenz, and R. Urtasun, *"Are We Ready for Autonomous Driving? The KITTI Vision Benchmark Suite"*, In Proc. of 25th IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pp. 3354-3361, Rhode Island, US, June 2012

[8] S. Hess, G. Segarra, K. Evensen, A. Festag, T. Weber, S. Cadzow, M. Arndt, and A. Wiles, *"Towards Standards for Sustainable ITS in Europe"*, 16th ITS World Congress and Exhibition, Stockholm, Sweden, September 2009

[9] J. B. Kenney, *"Dedicated Short-Range Communications (DSRC) Standards in the United States"*, Proceedings of the IEEE, vol. 99(7), 1162 – 1182, July 2011