Activity Report 2016

# Project-Team RITS

## Robotics & Intelligent Transportation Systems

RESEARCH CENTER
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THEME
**Robotics and Smart environments**

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## Project-Team RITS

*Creation of the Team: 2014 February 17, updated into Project-Team: 2015 July 01*

**Keywords:**

**Computer Science and Digital Science:**

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**Other Research Topics and Application Domains:**

5.6. - Robotic systems
6.5. - Information systems
6.6. - Embedded systems
7. - Transport and logistics

# 1. Members

**Research Scientists**

Fawzi Nashashibi [Team leader, Inria, Senior Researcher, HDR]
Guy Fayolle [Inria, Senior Researcher (emeritus)]
Jean-Marc Lasgouttes [Inria, Researcher]
Gérard Le Lann [Inria, Senior Researcher (emeritus)]
Vicente Milanés [Inria, Starting Research position, until Aug 2016]
Anne Verroust-Blondet [Inria, Researcher, HDR]

**Engineers**

Azary Abboud [Inria, Expert Engineer, from Feb 2016]
Raoul de Charette [Inria, Expert Engineer]
Pierre Merdrignac [Inria, Expert Engineer, until Sep 2016]
Oyunchimeg Shagdar [Inria, Expert Engineer, part time until Aug 2016]
Ahmed Soua [Inria, Expert Engineer, from Apr 2016]
Thomas Streubel [Inria, Expert Engineer, from Feb 2016]
Armand Yvet [Inria]

**PhD Students**

Mohammad Abualhoul [Inria, Mines ParisTech]
Zayed Alsayed [VEDECOM, Télécom ParisTech]
Pierre de Beaucorps [Inria granted by Valéo Etudes Electroniques, UPMC]
Carlos Flores [Inria, Mines ParisTech]
Fernando Garrido Carpio [VEDECOM, Mines ParisTech]
David González Bautista [Inria, Mines ParisTech]

Mohamed Maddouri [Inria, Univ. Rouen, until Jan 2016]
Francisco Navas [Inria, Mines ParisTech]
Dinh-Van Nguyen [grant from the Ministry of National Education of Vietnam, Mines ParisTech]
Danut-Ovidiu Pop [Inria, Univ. Rouen, from Jun 2016]
Guillaume Trehard [Inria granted by Valéo Etudes Electroniques, Mines ParisTech, until Feb 2016]

**Visiting Scientists**

Aidos Ibrayev [Kazakh National University, PhD Student, until Jun 2016]
Sakriani Watiasri Sakti [NAIST Japan, Assistant professor, until Mar 2016]

**Administrative Assistant**

Chantal Chazelas [Inria]

**Others**

Benjamin Boualam Murano [Min. de l'Education Nationale, student, until Apr 2016]
Rafael Colmenares Prieto [Inria, Engineering student, from Sep 2016]
Thierry Ernst [Yogoko, Research Engineer]
Aitor Gomez Torres [Inria, internship, from Sep 2016]
Juan Jose Larez Urdaneta [Inria, internship, from Aug 2016]
Pablo Marin Plaza [Inria, internship, from Sep 2016]
Kenneth Martinez Torres [Inria, internship, from Jun 2016 until Aug 2016]
Alexis Meyer [Inria, internship, from Mar 2016 until Sep 2016]
Daniel Sanchez Aranguren [Inria, internship, from Aug 2016]
Jose Emilio Traver Becerra [Inria, internship, until Jan 2016]
Myriam Vaca Recalde [Inria, internship, until Sep 2016]
Alfredo Valle Barrio [Inria, internship, from Sep 2016]
Itheri Yahiaoui [Univ. Reims, Assistant Professor]

# 2. Overall Objectives

## 2.1. Overall Objectives

The focus of the project-team is to develop the technologies linked to Intelligent Transportation Systems (ITS) with the objective to achieve sustainable mobility by the improvement of the safety, the efficiency of road transport according to the recent "Intelligent Vehicle Initiative" launched by the DG Information Society of the European Commission (for "Smarter, Cleaner, and Safer Transport"). More specifically, we want to develop, demonstrate and test some innovative technologies under the framework of LaRA, "La Route Automatisée [1]" which covers all the advanced driver assistance systems (ADAS) and the traffic management systems going all the way to fully automated vehicles.

These developments are all based on the sciences and technologies of information and communications (STIC) and have the objective to bring significant improvements in the road transport sector through incremental or breakthrough innovations. The project-team covers fundamental R&D work on key technologies, applied research to develop techniques that solve specific problems, and demonstrator activities to evaluate and disseminate the results.

The scientific approach is focused on the analysis and optimization of road transport systems through a double approach:

1. the control of individual road vehicles to improve locally their efficiency and safety,
2. the design and control of large transportation systems.

[1] LaRA is a Joint Research Unit (JRU) associating three French research teams: Inria's project-team RITS, Mines ParisTech's CAOR and LIVIC.

The first theme on vehicle control is broadly based on signal processing and data fusion in order to have a better machine understanding of the situation a vehicle may encounter, and on robotics techniques to control the vehicle in order to help (or replace) the driver to avoid accidents while improving the performance of the vehicle (speed, comfort, mileage, emissions, noise...). The theme also includes software techniques needed to develop applications in a real-time distributed and complex environment with extremely high safety standards. In addition, data must be exchanged between the vehicles; communication protocols have thus to be adapted to and optimized for vehicular networks characteristics (e.g. mobility, road safety requirements, heterogeneity, density), and communication needs (e.g. network latency, quality of service, network security, network access control).
The second theme on modeling and control of large transportation systems is also largely dependent on STIC. The objective, there, is to improve significantly the performance of the transportation system in terms of throughput but also in terms of safety, emissions, energy while minimizing nuisances. The approach is to act on demand management (e.g. through information, access control or road charging) as well as on the vehicles coordination. Communications technologies are essential to implement these controls and are an essential part of the R&D, in particular in the development of technologies for highly dynamic networks.

In order to address those issues simultaneously, RITS is organized into three research axes, each of which being driven by a separate sub-team. The first axis addresses the traditional problem of vehicle guidance and autonomous navigation. The second axis focuses on the large scale deployment and the traffic analysis and modeling. The third axis deals with the problem of telecommunications from two points of view:

- *Technical*: design certified architectures enabling safe vehicle-to-vehicle and vehicle-to-vehicle communications obeying to standards and norm;
- *Fundamental*, design and develop appropriate architectures capable of handling thorny problems of routing and geonetworking in highly dynamic vehicular networks and high speed vehicles.

Of course, these three research sub-teams interact to build intelligent cooperative mobility systems.

# 3. Research Program

## 3.1. Vehicle guidance and autonomous navigation

**Participants:** Zayed Alsayed, Pierre de Beaucorps, Raoul de Charette, Rafael Colmenares Prieto, Aitor Gomez Torres, Fernando Garrido Carpio, David González Bautista, Pierre Merdrignac, Alexis Meyer, Vicente Milanés, Francisco Navas, Fawzi Nashashibi, Carlos Flores, Dinh-Van Nguyen, Danut-Ovidiu Pop, Oyunchimeg Shagdar, Thomas Streubel, Guillaume Trehard, Anne Verroust-Blondet, Itheri Yahiaoui.

There are three basic ways to improve the safety of road vehicles and these ways are all of interest to the project-team. The first way is to assist the driver by giving him better information and warning. The second way is to take over the control of the vehicle in case of mistakes such as inattention or wrong command. The third way is to completely remove the driver from the control loop.

All three approaches rely on information processing. Only the last two involve the control of the vehicle with actions on the actuators, which are the engine power, the brakes and the steering. The research proposed by the project-team is focused on the following elements:

- perception of the environment,
- planning of the actions,
- real-time control.

### *3.1.1. Perception of the road environment*

**Participants:** Zayed Alsayed, Raoul de Charette, Rafael Colmenares Prieto, Aitor Gomez Torres, Pierre Merdrignac, Alexis Meyer, Fawzi Nashashibi, Dinh-Van Nguyen, Danut-Ovidiu Pop, Guillaume Trehard, Anne Verroust-Blondet, Itheri Yahiaoui.

Either for driver assistance or for fully automated guided vehicle purposes, the first step of any robotic system is to perceive the environment in order to assess the situation around itself. Proprioceptive sensors (accelerometer, gyrometer,...) provide information about the vehicle by itself such as its velocity or lateral acceleration. On the other hand, exteroceptive sensors, such as video camera, laser or GPS devices, provide information about the environment surrounding the vehicle or its localization. Obviously, fusion of data with various other sensors is also a focus of the research.
The following topics are already validated or under development in our team:

- relative ego-localization with respect to the infrastructure, i.e. lateral positioning on the road can be obtained by mean of vision (lane markings) and the fusion with other devices (e.g. GPS);
- global ego-localization by considering GPS measurement and proprioceptive information, even in case of GPS outage;
- road detection by using lane marking detection and navigable free space;
- detection and localization of the surrounding obstacles (vehicles, pedestrians, animals, objects on roads, etc.) and determination of their behavior can be obtained by the fusion of vision, laser or radar based data processing;
- simultaneous localization and mapping as well as mobile object tracking using laser-based and stereovision-based (SLAMMOT) algorithms.

Scene understanding is a large perception problem. In this research axis we have decided to use only computer vision as cameras have evolved very quickly and can now provide much more precise sensing of the scene, and even depth information. Two types of hardware setups were used, namely: monocular vision or stereo vision to retrieve depth information which allow extracting geometry information.

We have initiated several works:

- estimation of the ego motion using monocular scene flow. Although in the state of the art most of the algorithms use a stereo setup, researches were conducted to estimate the ego-motion using a novel approach with a strong assumption.
- bad weather conditions evaluations. Most often all computer vision algorithms work under a transparent atmosphere assumption which assumption is incorrect in the case of bad weather (rain, snow, hail, fog, etc.). In these situations the light ray are disrupted by the particles in suspension, producing light attenuation, reflection, refraction that alter the image processing.
- deep learning for object recognition. New works are being initiated in our team to develop deep learning recognition in the context of heterogeneous data.

### *3.1.2. Cooperative Multi-sensor data fusion*

**Participants:** Pierre Merdrignac, Fawzi Nashashibi, Oyunchimeg Shagdar.

Since data are noisy, inaccurate and can also be unreliable or unsynchronized, the use of data fusion techniques is required in order to provide the most accurate situation assessment as possible to perform the perception task. RITS team worked a lot on this problem in the past, but is now focusing on collaborative perception approach. Indeed, the use of vehicle-to-vehicle or vehicle-to-infrastructure communications allows an improved on-board reasoning since the decision is made based on an extended perception.

As a direct consequence of the electronics broadly used for vehicular applications, communication technologies are now being adopted as well. In order to limit injuries and to share safety information, research in driving assistance system is now orientating toward the cooperative domain. Advanced Driver Assistance System (ADAS) and Cybercars applications are moving towards vehicle-infrastructure cooperation. In such scenario, information from vehicle based sensors, roadside based sensors and a priori knowledge is generally combined thanks to wireless communications to build a probabilistic spatio-temporal model of the environment. Depending on the accuracy of such model, very useful applications from driver warning to fully autonomous driving can be performed.

The Collaborative Perception Framework (CPF) is a combined hardware/software approach that permits to see remote information as its own information. Using this approach, a communicant entity can see another remote entity software objects as if it was local, and a sensor object, can see sensor data of others entities as its own sensor data. Last year we developed the basic hardware modules that ensure the well functioning of the embedded architecture including perception sensors, communication devices and processing tools.

Finally, since vehicle localization (ground vehicles) is an important task for intelligent vehicle systems, vehicle cooperation may bring benefits for this task. A new cooperative multi-vehicle localization method using split covariance intersection filter was developed during the year 2012, as well as a cooperative GPS data sharing method.

In the first method, each vehicle estimates its own position using a SLAM (Simultaneous Localization And Mapping) approach. In parallel, it estimates a decomposed group state, which is shared with neighboring vehicles; the estimate of the decomposed group state is updated with both the sensor data of the ego-vehicle and the estimates sent from other vehicles; the covariance intersection filter which yields consistent estimates even facing unknown degree of inter-estimate correlation has been used for data fusion.

In the second GPS data sharing method, a new collaborative localization method is proposed. On the assumption that the distance between two communicative vehicles can be calculated with a good precision, cooperative vehicle are considered as additional satellites into the user position calculation by using iterative methods. In order to limit divergence, some filtering process is proposed: Interacting Multiple Model (IMM) is used to guarantee a greater robustness in the user position estimation.

Accidents between vehicles and pedestrians (including cyclists) often result in fatality or at least serious injury for pedestrians, showing the need of technology to protect vulnerable road users. Vehicles are now equipped with many sensors in order to model their environment, to localize themselves, detect and classify obstacles, etc. They are also equipped with communication devices in order to share the information with other road users and the environment. The goal of this work is to develop a cooperative perception and communication system, which merges information coming from the communications device and obstacle detection module to improve the pedestrian detection, tracking, and hazard alarming.

Pedestrian detection is performed by using a perception architecture made of two sensors: a laser scanner and a CCD camera. The laser scanner provides a first hypothesis on the presence of a pedestrian-like obstacle while the camera performs the real classification of the obstacle in order to identify the pedestrian(s). This is a learning-based technique exploiting adaptive boosting (AdaBoost). Several classifiers were tested and learned in order to determine the best compromise between the nature and the number of classifiers and the accuracy of the classification.

### 3.1.3. Planning and executing vehicle actions

**Participants:** Fernando Garrido Carpio, David González Bautista, Vicente Milanés, Fawzi Nashashibi, Francisco Navas, Carlos Flores.

From the understanding of the environment, thanks to augmented perception, we have either to warn the driver to help him in the control of his vehicle, or to take control in case of a driverless vehicle. In simple situations, the planning might also be quite simple, but in the most complex situations we want to explore, the planning must involve complex algorithms dealing with the trajectories of the vehicle and its surroundings (which might involve other vehicles and/or fixed or moving obstacles). In the case of fully automated vehicles, the perception will involve some map building of the environment and obstacles, and the planning will involve partial planning with periodical recomputation to reach the long term goal. In this case, with vehicle to vehicle communications, what we want to explore is the possibility to establish a negotiation protocol in order to coordinate nearby vehicles (what humans usually do by using driving rules, common sense and/or non verbal communication). Until now, we have been focusing on the generation of geometric trajectories as a result of a maneuver selection process using grid-based rating technique or fuzzy technique. For high speed vehicles, Partial Motion Planning techniques we tested, revealed their limitations because of the computational cost. The use of quintic polynomials we designed, allowed us to elaborate trajectories with different dynamics adapted to the driver profile. These trajectories have been implemented and validated in the JointSystem demonstrator of the German Aerospace Center (DLR) used in the European project HAVEit, as well as in RITS's electrical vehicle prototype used in the French project ABV. HAVEit was also the opportunity for RITS to take in charge the implementation of the Co-Pilot system which processes perception data in order to elaborate the high level command for the actuators. These trajectories were also validated on RITS's cybercars. However, for the low speed cybercars that have pre-defined itineraries and basic maneuvers, it was necessary to develop a more adapted planning and control system. Therefore, we have developed a nonlinear adaptive control for automated overtaking maneuver using quadratic polynomials and Lyapunov function candidate and taking into account the vehicles kinematics. For the global mobility systems we are developing, the control of the vehicles includes also advanced platooning, automated parking, automated docking, etc. For each functionality a dedicated control algorithm was designed (see publication of previous years). Today, RITS is also investigating the opportunity of fuzzy-based control for specific maneuvers. First results have been recently obtained for reference trajectories following in roundabouts and normal straight roads.

## 3.2. V2V and V2I Communications for ITS

**Participants:** Thierry Ernst, Oyunchimeg Shagdar, Gérard Le Lann, Pierre Merdrignac, Mohammad Abualhoul, Fawzi Nashashibi.

Wireless communications are expected to play an important role for road safety, road efficiency, and comfort of road users. Road safety applications often require highly responsive and reliable information exchange between neighboring vehicles in any road density condition. Because the performance of the existing radio communications technology largely degrades with the increase of the node density, the challenge of designing wireless communications for safety applications is enabling reliable communications in highly dense scenarios. Targeting this issue, RITS has been working on medium access control design and visible light communications, especially for highly dense scenarios. The works have been carried out considering the vehicle behavior such as vehicle merging and vehicle platooning.

Unlike many of the road safety applications, the applications regarding road efficiency and comfort of road users, on the other hand, often require connectivity to the Internet. Based on our expertise in both Internet-based communications in the mobility context and in ITS, we are now investigating the use of IPv6 (Internet Protocol version 6 which is going to replace the current version, IPv4, in a few years from now) for vehicular communications, in a combined architecture allowing both V2V and V2I.

The wireless channel and the topology dynamics need to be studied when understanding the dynamics and designing efficient communications mechanisms. Targeting this issue, we have been working on channel modeling for both radio and visible light communications, and design of communications mechanisms especially for security, service discovery, multicast and geocast message delivery, and access point selection.

Below follows a more detailed description of the related research issues.

### *3.2.1. Geographic multicast addressing and routing*

**Participants:** Oyunchimeg Shagdar, Thierry Ernst.

Many ITS applications such as fleet management require multicast data delivery. Existing work on this subject tackles mainly the problems of IP multicasting inside the Internet or geocasting in the VANETs. To enable Internet-based multicast services for VANETs, we introduced a framework that:
i) defines a distributed and efficient geographic multicast auto-addressing mechanism to ensure vehicular multicast group reachability through the infrastructure network,
ii) introduces a simplified approach that locally manages the group membership and distributes the packets among them to allow simple and efficient data delivery.

### *3.2.2. Platooning control using visible light communications*

**Participants:** Mohammad Abualhoul, Oyunchimeg Shagdar, Fawzi Nashashibi.

The main purpose of our research is to propose and test new successful supportive communication technology, which can provide stable and reliable communication between vehicles, especially for the platooning scenario. Although VLC technology has a short history in comparison with other communication technologies, the infrastructure availability and the presence of the congestion in wireless communication channels lead to propose VLC technology as a reliable and supportive technology which can takeoff some loads of the wireless radio communication. The first objective of this work is to develop an analytical model of VLC to understand its characteristics and limitations. The second objective is to design vehicle platooning control using VLC. In platooning control, a cooperation between control and communication is strongly required in order to guarantee the platoon's stability (e.g. string stability problem). For this purpose we work on VLC model platooning scenario, to permit for each vehicle the trajectory tracking of the vehicle ahead, altogether with a prescribed inter-vehicle distance and considering all the VLC channel model limitations. The integrated channel model of the main Simulink platooning model will be responsible for deciding the availability of the Line-of-Sight for different trajectory's curvatures, which means the capability of using light communication between each couple of vehicles in the platooning queue. At the same time the model will compute all the required parameters acquired from each vehicle controller.

### 3.2.3. V2X radio communications for road safety applications

**Participants:** Mohammad Abualhoul, Pierre Merdrignac, Oyunchimeg Shagdar, Fawzi Nashashibi.

While 5.9 GHz radio frequency band is dedicated to ITS applications, the channel and network behaviors in mobile scenarios are not very well known. In this work we theoretically and experimentally study the radio channel characteristics in vehicular networks, especially the radio quality and bandwidth availability. Based on our study, we develop mechanisms for efficient and reliable V2X communications, channel allocation, congestion control, and access point selection, which are especially dedicated to road safety and autonomous driving applications.

### 3.2.4. Safety-critical communications in intelligent vehicular networks

**Participant:** Gérard Le Lann.

Intelligent vehicular networks (IVNs) are constituents of ITS. IVNs range from platoons with a lead vehicle piloted by a human driver to fully ad-hoc vehicular networks, a.k.a. VANETs, comprising autonomous/automated vehicles. Safety issues in IVNs appear to be the least studied in the ITS domain. The focus of our work is on safety-critical (SC) scenarios, where accidents and fatalities inevitably occur when such scenarios are not handled correctly. In addition to on-board robotics, inter-vehicular radio communications have been considered for achieving safety properties. Since both technologies have known intrinsic limitations (in addition to possibly experiencing temporary or permanent failures), using them redundantly is mandatory for meeting safety regulations. Redundancy is a fundamental design principle in every SC cyber-physical domain, such as, e.g., air transportation. (Optics-based inter-vehicular communications may also be part of such redundant constructs.) The focus of our on-going work is on safety-critical (SC) communications. We consider IVNs on main roads and highways, which are settings where velocities can be very high, thus exacerbating safety problems acceptable delays in the cyber space, and response times in the physical space, shall be very small. Human lives being at stake, such delays and response times must have strict (non-stochastic) upper bounds under worst-case conditions (vehicular density, concurrency and failures). Consequently, we are led to look for deterministic solutions.

**Rationale**

In the current ITS literature, the term *safety* is used without being given a precise definition. That must be corrected. In our case, a fundamental open question is: what is the exact meaning of *SC communications*? We have devised a definition, referred to as space-time bounds acceptability (STBA) requirements. For any given problem related to SC communications, those STBA requirements serve as yardsticks for distinguishing acceptable solutions from unacceptable ones with respect to safety. In conformance with the above, STBA requirements rest on the following worst-case upper bounds: $\lambda$ for channel access delays, and $\Delta$ for distributed inter-vehicular coordination (message dissemination, distributed agreement).

Via discussions with foreign colleagues, notably those active in the IEEE 802 Committee, we have comforted our early diagnosis regarding existing standards for V2V/V2I/V2X communications, such as IEEE 802.11p and ETSI ITS-G5: they are totally inappropriate regarding SC communications. A major flaw is the choice of CSMA/CA as the MAC-level protocol. Obviously, there cannot be such bounds as $\lambda$ and $\Delta$ with CSMA/CA. Another flaw is the choice of medium-range omnidirectional communications, radio range in the order of 250 m, and interference range in the order of 400 m. Stochastic delays achievable with existing standards are just unacceptable in moderate/worst-case contention conditions. Consider the following setting, not uncommon in many countries: a highway, 3 lanes each direction, dense traffic, i.e. 1 vehicle per 12.5 m. A simple calculation leads to the following result: any vehicle may experience (destructive) interferences from up to 384 vehicles. Even if one assumes some reasonable communications activity ratio, say 25%, one finds that up to 96 vehicles may be contending for channel access. Under such conditions, MAC-level delays and string-wide dissemination/agreement delays achieved by current standards fail to meet the STBA requirements by huge margins.

Reliance on V2I communications via terrestrial infrastructures and nodes, such as road-side units or WiFi hotspots, rather than direct V2V communications, can only lead to poorer results. First, reachability is not guaranteed: hazardous conditions may develop anywhere anytime, far away from a terrestrial node. Second, mixing SC communications and ordinary communications within terrestrial nodes is a violation of the very fundamental segregation principle: SC communications and processing shall be isolated from ordinary communications and processing. Third, security: it is very easy to jam or to spy on a terrestrial node; moreover, terrestrial nodes may be used for launching all sorts of attacks, man-in-the-middle attacks for example. Fourth, delays can only get worse than with direct V2V communications, since transiting via a node inevitably introduces additional latencies. Fifth, the delivery of every SC message must be acknowledged, which exacerbates the latency problems. Sixth, availability: what happens when a terrestrial node fails?

Trying to tweak existing standards for achieving SC communications is vain. That is also unjustified. Clearly, medium-range omnidirectional communications are unjustified for the handling of SC scenarios. By definition, accidents can only involve vehicles that are very close to each other. Therefore, short-range directional communications suffice. The obvious conclusion is that novel protocols and inter-vehicular coordination algorithms based on short-range direct V2V communications are needed. It is mandatory to check whether these novel solutions meet the STBA requirements. Future standards specifically aimed at SC communications in IVNs may emerge from such solutions.

**Naming and privacy**

Additionally, we are exploring the (re)naming problem as it arises in IVNs. Source and destination names appear in messages exchanged among vehicles. Most often, names are IP addresses or MAC addresses (plate numbers shall not be used for privacy reasons). A vehicle which intends to communicate with some vehicle, denoted $V$ here, must know which name *name(V)* to use in order to reach/designate $V$. Existing solutions are based on multicasting/broadcasting existential messages, whereby every vehicle publicizes its existence (name and geolocation), either upon request (replying to a Geocast) or spontaneously (periodic beaconing). These solutions have severe drawbacks. First, they contribute to overloading communication channels (leading to unacceptably high worst-case delays). Second, they amount to breaching privacy voluntarily. Why should vehicles reveal their existence and their time dependent geolocations, making tracing and spying much easier? Novel solutions are needed. They shall be such that:

- At any time, a vehicle can assign itself a name that is unique within a geographical zone centered on that vehicle (no third-party involved),
- No linkage may exist between a name and those identifiers (plate numbers, IP/MAC addresses, etc.) proper to a vehicle,
- Different (unique) names can be computed at different times by a vehicle (names can be short-lived or long-lived),
- *name(V)* at UTC time $t$ is revealed only to those vehicles sufficiently close to $V$ at time $t$, notably those which may collide with $V$.

We have solved the (re)naming problem in string/cohort formations [48]. Ranks (unique integers in any given string/cohort) are privacy-preserving names, easily computed by every member of a string, in the presence of string membership changes (new vehicles join in, members leave). That problem is open when considering arbitrary clusters of vehicles/strings encompassing multiple lanes.

## 3.3. Probabilistic modeling for large transportation systems

**Participants:** Guy Fayolle, Jean-Marc Lasgouttes.

This activity concerns the modeling of random systems related to ITS, through the identification and development of solutions based on probabilistic methods and more specifically through the exploration of links between large random systems and statistical physics. Traffic modeling is a very fertile area of application for this approach, both for macroscopic (fleet management [46], traffic prediction) and for microscopic (movement of each vehicle, formation of traffic jams) analysis. When the size or volume of structures grows (leading to the so-called “thermodynamic limit”), we study the quantitative and qualitative (performance, speed, stability, phase transitions, complexity, etc.) features of the system.

In the recent years, several directions have been explored.

### *3.3.1. Traffic reconstruction*

Large random systems are a natural part of macroscopic studies of traffic, where several models from statistical physics can be fruitfully employed. One example is fleet management, where one main issue is to find optimal ways of reallocating unused vehicles: it has been shown that Coulombian potentials might be an efficient tool to drive the flow of vehicles. Another case deals with the prediction of traffic conditions, when the data comes from probe vehicles instead of static sensors.

While the widely-used macroscopic traffic flow models are well adapted to highway traffic, where the distance between junction is long (see for example the work done by the NeCS team in Grenoble), our focus is on a more urban situation, where the graphs are much denser. The approach we are advocating here is model-less, and based on statistical inference rather than fundamental diagrams of road segments. Using the Ising model or even a Gaussian Random Markov Field, together with the very popular Belief Propagation (BP) algorithm, we have been able to show how real-time data can be used for traffic prediction and reconstruction (in the space-time domain).

This new use of BP algorithm raises some theoretical questions about the ways the make the belief propagation algorithm more efficient:

- find the best way to inject real-valued data in an Ising model with binary variables [50];
- build macroscopic variables that measure the overall state of the underlying graph, in order to improve the local propagation of information [47];
- make the underlying model as sparse as possible, in order to improve BP convergence and quality [49].

### *3.3.2. Exclusion processes for road traffic modeling*

The focus here is on road traffic modeled as a granular flow, in order to analyze the features that can be explained by its random nature. This approach is complementary to macroscopic models of traffic flow (as done for example in the Opale team at Inria), which rely mainly on ODEs and PDEs to describe the traffic as a fluid.

One particular feature of road traffic that is of interest to us is the spontaneous formation of traffic jams. It is known that systems as simple as the Nagel-Schreckenberg model are able to describe traffic jams as an emergent phenomenon due to interaction between vehicles. However, even this simple model cannot be explicitly analyzed and therefore one has to resort to simulation.

One of the simplest solvable (but non trivial) probabilistic models for road traffic is the exclusion process. It lends itself to a number of extensions allowing to tackle some particular features of traffic flows: variable speed of particles, synchronized move of consecutive particles (platooning), use of geometries more complex than plain 1D (cross roads or even fully connected networks), formation and stability of vehicle clusters (vehicles that are close enough to establish an ad-hoc communication system), two-lane roads with overtaking.

The aspect that we have particularly studied is the possibility to let the speed of vehicle evolve with time. To this end, we consider models equivalent to a series of queues where the pair (service rate, number of customers) forms a random walk in the quarter plane $\mathbb{Z}_+^2$.

Having in mind a global project concerning the analysis of complex systems, we also focus on the interplay between discrete and continuous description: in some cases, this recurrent question can be addressed quite rigorously via probabilistic methods.

We have considered in [43] some classes of models dealing with the dynamics of discrete curves subjected to stochastic deformations. It turns out that the problems of interest can be set in terms of interacting exclusion processes, the ultimate goal being to derive hydrodynamic limits after proper scaling. A seemingly new method is proposed, which relies on the analysis of specific partial differential operators, involving variational calculus and functional integration. Starting from a detailed analysis of the Asymmetric Simple Exclusion Process (ASEP) system on the torus $\mathbb{Z}/n\mathbb{Z}$, the arguments a priori work in higher dimensions (ABC, multi-type exclusion processes, etc), leading to systems of coupled partial differential equations of Burgers' type.

### 3.3.3. Random walks in the quarter plane $\mathbb{Z}_+^2$

This field remains one of the important *"violon d'Ingres"* in our research activities in stochastic processes, both from theoretical and applied points of view. In particular, it is a building block for models of many communication and transportation systems.

One essential question concerns the computation of stationary measures (when they exist). As for the answer, it has been given by original methods formerly developed in the team (see books and related bibliography). For instance, in the case of small steps (jumps of size one in the interior of $\mathbb{Z}_+^2$), the invariant measure $\{\pi_{i,j}, i,j \geq 0\}$ does satisfy the fundamental functional equation (see [45]):

$$Q(x,y)\pi(x,y) = q(x,y)\pi(x) + \widetilde{q}(x,y)\widetilde{\pi}(y) + \pi_0(x,y). \tag{1}$$

where the unknown generating functions $\pi(x,y), \pi(x), \widetilde{\pi}(y), \pi_0(x,y)$ are sought to be analytic in the region $\{(x,y) \in \mathbb{C}^2 : |x| < 1, |y| < 1\}$, and continuous on their respective boundaries.

The given function $Q(x,y) = \sum_{i,j} p_{i,j} x^i y^j - 1$, where the sum runs over the possible jumps of the walk inside $\mathbb{Z}_+^2$, is often referred to as the *kernel*. Then it has been shown that equation (1) can be solved by reduction to a boundary-value problem of Riemann-Hilbert type. This method has been the source of numerous and fruitful developments. Some recent and ongoing works have been dealing with the following matters.

- *Group of the random walk*. In several studies, it has been noticed that the so-called *group of the walk* governs the behavior of a number of quantities, in particular through its *order*, which is always even. In the case of small jumps, the algebraic curve $R$ defined by $\{Q(x,y) = 0\}$ is either of *genus* 0 (the sphere) or 1 (the torus). In [Fayolle-2011a], when the drift of the random walk is equal to 0 (and then so is the genus), an effective criterion gives the *order* of the group. More generally, it is also proved that whenever the genus is 0, this order is infinite, except precisely for the zero drift case, where finiteness is quite possible. When the *genus* is 1, the situation is more difficult. Recently [44], a criterion has been found in terms of a determinant of order 3 or 4, depending on the arity of the group.
- *Nature of the counting generating functions*. Enumeration of planar lattice walks is a classical topic in combinatorics. For a given set of allowed jumps (or steps), it is a matter of counting the number of paths starting from some point and ending at some arbitrary point in a given time, and possibly restricted to some regions of the plane. A first basic and natural question arises: how many such paths

exist? A second question concerns the nature of the associated counting generating functions (CGF): are they rational, algebraic, holonomic (or D-finite, i.e. solution of a linear differential equation with polynomial coefficients)?

Let $f(i,j,k)$ denote the number of paths in $\mathbb{Z}_+^2$ starting from $(0,0)$ and ending at $(i,j)$ at time $k$. Then the corresponding CGF

$$F(x,y,z) = \sum_{i,j,k\geq 0} f(i,j,k)x^i y^j z^k \qquad (2)$$

satisfies the functional equation

$$K(x,y)F(x,y,z) = c(x)F(x,0,z) + \widetilde{c}(y)F(0,y,z) + c_0(x,y), \qquad (3)$$

where $z$ is considered as a time-parameter. Clearly, equations (2) and (1) are of the same nature, and answers to the above questions have been given in [Fayolle-2010].

- *Some exact asymptotics in the counting of walks in* $\mathbb{Z}_+^2$. A new and uniform approach has been proposed about the following problem: *What is the asymptotic behavior, as their length goes to infinity, of the number of walks ending at some given point or domain (for instance one axis)?* The method in [Fayolle-2012] works for *both* finite or infinite groups, and for walks not necessarily restricted to excursions.

### *3.3.4. Discrete-event simulation for urban mobility*

We have developed two simulation tools to study and evaluate the performance of different transportation modes covering an entire urban area.

- one for collective taxis, a public transportation system with a service quality provided will be comparable with that of conventional taxis (system operating with or without reservations, door-to-door services, well adapted itineraries following the current demand, controlling detours and waits, etc.), and with fares set at rates affordable by almost everyone, simply by utilizing previously wasted vehicle capacity;
- the second for a system of self-service cars that can reconfigure themselves into shuttles, therefore creating a multimodal public transportation system; this second simulator is intended to become a generic tool for multimodal transportation.

These two programs use a technique allowing to run simulations in batch mode and analyze the dynamics of the system afterward.

# 4. Application Domains

## 4.1. Introduction

While the preceding section focused on methodology, in connection with automated guided vehicles, it should be stressed that the evolution of the problems which we deal with, remains often guided by the technological developments.We enumerate three fields of application, whose relative importance varies with time and which have strong mutual dependencies: driving assistance, cars available in self-service mode and fully automated vehicles (cybercars).

## 4.2. Driving assistance

Several techniques will soon help drivers. One of the first immediate goal is to improve security by alerting the driver when some potentially dangerous or dangerous situations arise, i.e. collision warning systems or lane tracking could help a bus driver and surrounding vehicle drivers to more efficiently operate their vehicles. Human factors issues could be addressed to control the driver workload based on additional information processing requirements. Another issue is to optimize individual journeys. This means developing software for calculating optimal (for the user or for the community) paths. Nowadays, path planning software is based on a static view of the traffic: efforts have to be done to take the dynamic component in account.

## 4.3. New transportation systems

The problems related to the abusive use of the individual car in large cities led the populations and the political leaders to support the development of public transport. A demand exists for a transport of people and goods which associates quality of service, environmental protection and access to the greatest number. Thus the tram and the light subways of VAL type recently introduced into several cities in France conquered the populations, in spite of high financial costs. However, these means of mass transportation are only possible on lines on which there is a keen demand. As soon as one moves away from these “lines of desire” or when one deviates from the rush hours, these modes become expensive and offer can thus only be limited in space and time. To give a more flexible offer, it is necessary to plan more individual modes which approach the car as we know it. However, if one wants to enjoy the benefits of the individual car without suffering from their disadvantages, it is necessary to try to match several criteria: availability anywhere and anytime to all, lower air and soils pollution as well as sound levels, reduced ground space occupation, security, low cost. Electric or gas vehicles available in self-service, as in the Praxitèle system, bring a first response to these criteria. To be able to still better meet the needs, it is however necessary to re-examine the design of the vehicles on the following points:

- ease empty car moves to better distribute them;
- better use of information systems inboard and on ground;
- better integrate this system in the global transportation system.

These systems are now operating (i.e. in La Rochelle). The challenge is to bring them to an industrial phase by transferring technologies to these still experimental projects.

## 4.4. Automated vehicles

The long term effort of the project is to put automatically guided vehicles (cybercars) on the road. It seems too early to mix cybercars and traditional vehicles, but data processing and automation now make it possible to consider in the relatively short term the development of such vehicles and the adapted infrastructures. RITS aims at using these technologies on experimental platforms (vehicles and infrastructures) to accelerate the technology transfer and to innovate in this field. Other application can be precision docking systems that will allow buses to be automatically maneuvered into a loading zone or maintenance area, allowing easier access for passengers, or more efficient maintenance operations. Transit operating costs will also be reduced through decreased maintenance costs and less damage to the braking and steering systems. Regarding technical topics, several aspects of Cybercars have been developed at RITS this year. First, we have stabilized a generic Cycab architecture involving Inria SynDEx tool and CAN communications. The critical part of the vehicle is using a real-time SynDEx application controlling the actuators via two Motorola’s MPC555. Today, we have decided to migrate to the new dsPIC architecture for more efficiency and ease of use. This application has a second feature, it can receive commands from an external source (Asynchronously to this time) on a second CAN bus. This external source can be a PC or a dedicated CPU, we call it high level. To work on the high level, in the past years we have been developing a R&D framework called (Taxi) which used to take control of the vehicle (Cycab and Yamaha) and process data such as gyro, GPS, cameras, wireless communications and so on. Today, in order to rely on a professional and maintained solution, we have chosen to migrate to the RTMaps SDK development platform. Today, all our developments and demonstrations are using this efficient prototyping platform. Thanks to RTMaps we have been able to do all the demonstrations on our cybercars: cycabs, Yamaha AGV and new Cybus platforms. These demonstrations include: reliable SLAMMOT algorithm using 2 to 4 laser sensors simultaneously, automatic line/road following techniques, PDA remote control, multi sensors data fusion, collaborative perception via ad-hoc network. The second main topic is inter-vehicle communications using ad-hoc networks. We have worked with the EVA team for setting and tuning OLSR, a dynamic routing protocol for vehicles communications. Our goal is to develop a vehicle dedicated communication software suite, running on a specialized hardware. It can be linked also with the Taxi Framework for getting data such GPS information's to help the routing algorithm.

# 5. New Software and Platforms

## 5.1. DOLAR

FUNCTIONAL DESCRIPTION

This software performs real-time obstacle detection and tracking using laser data scanned with one or several laser sensors with different geometric configurations. Obstacle detection is based on laser data segmentation while obstacle tracking uses PHD-based filtering techniques.

- Authors: Raoul de Charette, Fawzi Nashashibi and Evangeline Pollard
- Contact: Fawzi Nashashibi

## 5.2. FEMOT

Fuzzy Embedded MOTor
FUNCTIONAL DESCRIPTION

FEMOT is an experimental motor for implementing fuzzy logic controllers, including all the fuzzy stages (fuzzification, inference, and defuzzification). This library has been compiled in Microsoft Visual (MVS) Studio and RTMaps. The proposed library is modular and adaptable to different situations and scenarios, especially for autonomous driving applications. FEMOT allows the development of the fuzzy rules to be written as sentences in an almost natural language. It allows the user to define variables and their fuzzy rules and to join them with other variables in rules to yield crisp signals for the controllers.

This software is used for the arbitration and control for fully automated functions. The behaviour of a human driver can be emulated with this technique. First simulations are showing promising results, and the library allows an easy adaptation in decision marking situations.

- Participants: Joshue Perez Rastelli and Vicente Milanés
- Contact: Fawzi Nashashibi

## 5.3. MELOSYM

FUNCTIONAL DESCRIPTION

MELOSYM is the latest laser based Hierarchical ML-SLAM algorithm developed by RITS. It contains all the functions needed to perform the vehicle localization and the mapping of the environment. Windows compatible, it was initially developed under the RTMAPS platform but the version includes a standalone version.

- Participants: Fawzi Nashashibi, Benjamin Lefaudeux, Jianping Xie and Paulo Lopes Resende
- Contact: Fawzi Nashashibi

## 5.4. PML-SLAM

- Participants: Zayed Alsayed and Fawzi Nashashibi
- Contact: Fawzi Nashashibi

## 5.5. Platools

KEYWORD: Telecommunications

- Participant: Marios Makassikis
- Contact: Thierry Ernst

## 5.6. SODA

SOftwares for Driving Automation
KEYWORD: Environment perception
FUNCTIONAL DESCRIPTION

This software has been developed in the context of the French ABV (Automatisation Basse Vitesse) project. This package contains the functions that are necessary to automate the vehicle navigation in its secured lane.

- Participants: Paulo Lopes Resende and Fawzi Nashashibi
- Contact: Fawzi Nashashibi

## 5.7. STEREOLOC-3D

FUNCTIONAL DESCRIPTION

STEREOLOC is the package performing stereovision based localization and mapping. It performs semi-dense mapping of outdoor large environments and provides real-time estimates of the vehicle position.

- Participants: Benjamin Lefaudeux and Fawzi Nashashibi
- Contact: Fawzi Nashashibi

## 5.8. Taxi-col

KEYWORD: Mobile Computing, Transportation

- Participant: Eugenie Lioris
- Contact: Fawzi Nashashibi

## 5.9. V2Provue

Vehicle-to-Pedestrian
FUNCTIONAL DESCRIPTION

It is a software developed for the Vehicle-to-Pedestrian (V2P) communications, risk calculation, and alarming pedestrians of collision risk. This software is made of an Android application dedicated to pedestrians and RtMaps modules for the vehicles.

On the pedestrian side, the application is relying on GPS data to localize the user and Wi-Fi communications are used to receive messages about close vehicles and send information about the pedestrian positioning. Besides, a service has been developed to evaluate the collision risk with the vehicles near the pedestrian and an HMI based on OpenStreetMap displays all the useful information such as pedestrian and vehicles localization and, collision risk.

On the vehicle side, RtMaps modules allowing V2X communications have been developed. These modules contain features such as TCP/UDP socket transmissions, broadcast, multicast, unicast communications, routing, forwarding algorithms, and application specific modules. In the V2ProVu software, a particular application module has been implemented to create data packets containing information about the vehicle state (position, speed, yaw rate,...) and the V2X communication stack is used to broadcast these packets towards pedestrians. Moreover, the V2proVu application can also receive data from pedestrians and create objects structures that can be shared with the vehicle perception tools.

- Contact: Fawzi Nashashibi

## 5.10. SimConVA

**Participants:** Pierre Merdrignac, Oyunchimeg Shagdar, Jean-Marc Lasgouttes.

This software was developed during the SINETIC FUI project. It aims at interfacing the network simulator ns-3 and the prototyping software RTMaps.

The source code of is software is a library to generate an RTMaps component that triggers and controls ns-3. The component handle emission and reception of data packets between RTMaps and ns-3 for every vehicle. It can also deal with the mobility of vehicles in ns-3 based on the localization known in ns-3.

This software was used with the communication stack developed in RITS. It has been shown during the SINETIC project how this it can be used for simulating and emulating cooperative driver assistance systems. Particularly, the software has been tested on cooperative platoons. The tests were conducted on both simulation and real platforms to prove how the such software can be used during the development phase and that it is fully compatible with the architecture already present in the experimental vehicles.

- Contact: Fawzi Nashashibi

# 6. New Results

## 6.1. Low Speed Vehicle Localization using WiFi-FingerPrinting

**Participants:** Dinh-Van Nguyen, Myriam Vaca Recalde, Fawzi Nashashibi.

Recently, the problem of fully autonomous navigation of vehicle has gained major interest from research institutes and private companies. In general, these researches rely on GPS in fusion with other sensors to track vehicle in outdoor environment. However, as indoor environment such as car park is also an important scenario for vehicle navigation, the lack of GPS poses a serious problem. In [39] we present an approach to use WiFi Fingerprinting as a replacement for GPS information in order to allow seamlessly transition of localization architecture from outdoor to indoor environment. Often, movement speed of vehicle in indoor environment is low (10-12km/h) in comparison to outdoor scene but still surpasses human walking speed (3-5km/h, which is usually maximum movement speed for effective WiFi localization). We propose an ensemble classification method together with a motion model in order to deal with the above issue. Experiments show that proposed method is capable of imitating GPS behavior on vehicle tracking.

## 6.2. Free navigation space estimation

**Participants:** Raoul de Charette, Rafael Colmenares Prieto, Alexis Meyer, Fawzi Nashashibi.

Autonomous vehicles need to know where they can physically drive. In the past, lane detection was used to bound the driving area of the vehicle but road markings do not exist in many urban scenario thus perception needs to estimate the free navigation space with other means.

To contrast with the state of the art two approaches were developed and will be published soon. The first approach is using a monocular setup and use an absurd logic to identify the flow of the scene and extract the ego motion. The second method still under research is to develop a hybrid approach to segment the navigation space using energy minimization to label the scene assuming learning on the go.

## 6.3. Pedestrian Recognition using Convolutional Neural Networks

**Participants:** Danut-Ovidiu Pop, Fawzi Nashashibi.

Pedestrian detection is of highly importance for a large number of applications, especially in the elds of automotive safety, robotics and surveillance. In spite of the widely varying methods developed in recent years, pedestrian detection is still an open challenge whose accuracy and robustness has to be improved. This year we focused on the improvement of the classification component in the pedestrian detection task by adopting two approaches: 1) by combining three image modalities (intensity, depth and ow) to feed a unique convolutional neural network (CNN) and 2) by fusing the results of three independent CNNs. The evaluations have been performed on the Daimler stereo vision data set.

## 6.4. Reliability estimation and information redundancy for accurate localization

**Participants:** Zayed Alsayed, Anne Verroust-Blondet, Fawzi Nashashibi.

Our goal is to improve localization systems performances in order to be able to navigate in urban and peri-urban environments. For this purpose, we choose to study the reliability of a SLAM method that incrementally builds a map of the surrounding environment from an information given by a set of 2D laser points.
This year, we focused on SLAM failure and non-failure scenarios.

- Experimental data acquired on the VEDECOM demonstrator in the context of ITS Bordeaux demonstrations in 2015 were analyzed. This evaluation showed in [30] that the SLAM concept seems better suited to urban scenarios, while algorithms such as lane marking detection could offer a good alternative in peri-urban environments.
- In parallel, we worked on designing a reliability measure associated to the pose given by our SLAM considering the geometrical configurations of the 2D laser points describing the environment and the computations done in the maximum likelihood matching process.

## 6.5. Feature Selection for road obstacles classification

**Participants:** Itheri Yahiaoui, Pierre Merdrignac, Anne Verroust-Blondet.

In order to ensure the ability of an automated vehicle to be autonomous in a real environment, we must equip it with tools (hardware and software) to meet the requirement of such an application as safety, real-time processing, understanding and intelligence, etc. To contribute to these objectives a perception system is of vital importance. The one on road obstacles detection and classification is of particular interest for us. In this work a large number of geometric features have been proposed to describe different class objects like vehicles, pedestrians, cyclists and static obstacles from 2D laser points. A binary classification was performed with an Adaboost algorithm. In order to improve this work and enhance the classification rate, we have constructed new binary and multiclass classifiers, using SVM and logistic regression, with optimal choices of kernel parameters and models. We have defined several decision strategies by tracking objects in the video sequences, which lead to obtain the most probable target object. On the other hand, we have studied different dependence measures between the proposed features and the classes, leading the selection of the best set of features. As measures of dependence, we have used nonparametric estimate of mutual information, Fisher information and Pearson correlation. We have used also the Akaïke criterion in order to select the best models (the best subset of features) in logistic regression.

## 6.6. Motion planning techniques

**Participants:** David González Bautista, Fernando Garrido Carpio, Vicente Milanés, Fawzi Nashashibi, Myriam Vaca Recalde, Jose Emilio Traver Becerra.

The latest developments in the Intelligent Transportation Systems (ITS) field allow emerging technologies to show promising results at increasing passengers comfort and safety, while decreasing energy consumption, emissions and travel time. Despite of great efforts, fully automated driving still remains unsolved, where research challenges such as navigation in urban dynamic environments with obstacle avoidance capabilities–i.e. Vulnerable Road Users (VRU) and vehicles–and cooperative maneuvers among automated and semi-automated vehicles, still need further efforts for a real environment implementation. A deep state-of-the-art review has been conducted to find the gaps in this important topic into the autonomous vehicle field, with special attention to overtaking and obstacle avoidance maneuvers [21].

Having this in mind, a novel local path planning algorithm combining both off-line and real-time generation has been proposed in [32], providing a significant reduction on the computational time with respect to prior implementations from RITS team. This new local planning architecture for urban environments benefits from *a priori* knowledge of the geometry of the road layout, vehicle's kinematics and dynamics, among others, to produce local smooth path for the vehicle to navigate. The planner relies on several databases containing optimized trajectories for a $G^2$ continuous path generation. Four different type of databases have been generated to provide our system with a naturalistic driving style, allowing the car to maintain smooth trajectories according to the characteristics of the road [33].

Based on the accuracy of current digital maps, it is possible to know before-hand the way-points that define the route by which the vehicle will pass to reach a predefined destination. Furthermore, the original route can be generated in real-time and modified on-demand according to the user needs through the use of Automatic Global Planners (AGP) [42]. That way, since urban scenarios can present several consecutive curves in a short period of time, a smoother and more comfortable path generation can be done by extending the planning horizon up to two curves. There, a set of paths are analyzed by considering the angles of the curves and the distances to them in order to find the best joint point for the consecutive curves.

In this sense, a speed planning algorithm has also been designed to increase passenger comfort and set continuous speed profiles [35]. The approach permits to improve the comfort in automated vehicles by integrating the speed profile with the previously computed path, constraining the global acceleration in the whole ride (longitudinal and lateral accelerations according to ISO 2631-1). It also minimizes distance error problems by associating the speed profile w.r.t. distance in the path instead of the time. The planner has been tested against other techniques in the state-of-the-art, providing better results.

The proposed architecture has been validated both on simulation (with Pro-Sivic and RTMaps) and on the Inria Rocquencourt terrain. The results showed a smoother tracking of the curves, reduction on the execution times and reduced global accelerations increasing comfort. Future works will improve the capacity to deal with dynamic obstacles, conducting avoidance maneuvers if possible, or returning to the original lane if not. The maneuver will be decided by building an occupancy grid with the information given by the perception system. It will provide the best point near the obstacle to carry out the avoidance trajectory by loading the pre-computed curves.

## 6.7. Plug&Play control for highly non-linear systems: Stability analysis of autonomous vehicles

**Participants:** Francisco Navas, Vicente Milanés, Fawzi Nashashibi.

The final stage for automating a vehicle relies on the control algorithms. They are in charge of providing the proper behavior and performance to the vehicle, leading to provide fully automated capabilities. Controllability and stability of dynamic complex systems are the key aspects when it comes to design intelligent control algorithms for vehicles.

Nowadays, the problem is that control systems are "monolithic". That means that a minor change in the system could require the entire redesign of the control system. It addresses a major challenge, a system able to adapt the control structure automatically when a change occurred.

An autonomous vehicle is built by combining a set-of-sensors and actuators together with sophisticated algorithms. Since sensors and actuators are prone to intermittent faults, the use of different sensors is better and more cost effective than duplicating the same sensor type. The problem is to deal with the different availability of each sensor/actuator and how the vehicle should react to these changes. A methodology that improves the security of autonomous driving systems by providing a framework managing different sensor/actuator setups should be carried out. New trends are proposing intelligent algorithms able to handle any unexpected circumstances as unpredicted uncertainties or even fully outages from sensors. This is the case of Plug&Play control, which is able to provide stability responses for autonomous vehicles under uncontrolled circumstances, including modifications on the input/output sensors.

In order to meet with the idea of automatically handling those changes into the system, different research lines should be followed:

- Reconfiguration of existing controllers whenever changes are introduced in the system being controlled. In that line, the already commercially available Adaptive Cruise Controller (ACC) system, and its evolution by adding vehicle-to-vehicle communication (CACC) are examined. Plug&Play control is used for providing stable transitions between both controllers when the vehicle-to-vehicle communication link is changing from available to available or vice versa. More detail can be found in [38]. Gain scheduling approaches can be achieved by using the same structure. An Advanced-CACC is developed by using it. Hybrid behaviors between controllers with different head times are carried out depending on the traffic situation.
- Online closed loop identification of the vehicle and its components. Plug&Play control also provides a way for doing online closed loop identification of any system as open loop like systems. Here, the obtained models for the vehicle will be compared with the physical lateral model (Bicycle and 2GDL) and the longitudinal model together with the tire models (Pacejka, Dugoff and Buckhardt). It is also possible to identify new sensors or actuators connected to the system.
- Automatic control reconfiguration to achieve optimal performance together with identification of the new situation. Once a new situation has been identified in the system, the controller should be reconfigured to achieve the optimal performance of the autonomous vehicle.

## 6.8. Using Fractional Calculus for Cooperative Car Following Control

**Participants:** Carlos Flores, Vicente Milanés, Fawzi Nashashibi.

In the field of Advanced Driver Assistance Systems (ADAS), there are two main types of systems: passive and active ones. Specifically the active ADAS, they are capable of taking partial or complete control of the vehicle. Among these techniques, Car-Following has arisen as one important solution to traffic jams, driver comfort and safety.

Scoping on the evolution of the control involved in Car Following, it can be remarked the improved version of the cruise control system, Adaptive Cruise Control (ACC). This system allows the vehicle to maintain a desired distance gap measured by raging sensors (LiDAR, radars, etc), by controlling longitudinally the vehicle through the throttle and brake.

Afterward, the addition of Vehicle to Vehicle (V2V) communication links allowed the vehicles to maintain even shorter distances between each of the string members, by performing a Cooperative ACC (CACC). Focusing on CACC formations, a control structure must be conceived to guarantee stability and string stability as well. As a core of the control structure, the controller must be able to maintain the vehicle in the desired spacing in a stable, robust and comfortable.

Towards achieving this goals, it is proposed to use fractional order calculus to gain a more flexible frequency response and at the same time satisfy more demanding design requirements. This mathematical has been used for years for different applications providing good results and outperforming classical techniques in the industrial control field, due to its capability of describing systems more accurately than integer order calculus. Several research lines are stated to achieve these objectives:

- An exhaustive identification process of the experimental platforms dynamics. Allowing further comparison between the empirical identified dynamics of the real vehicle and a theoretical mathematical dynamic model. Such permits to design much more effective and stable control algorithms for both the lateral and longitudinal command of the vehicle.
- Conception of a Car-Following gap regulation controller using fractional order calculus, which has been proven that yields a more accurate description of real processes. The controller should satisfy more demanding design requirements [31], allowing to extend the scope of Car Following controllers' design. This controller should be framed into an appropriate control structure both for ACC and CACC
- Further investigation on the effects of communication delays and latency in the V2V links, as well as study different control structures that react not with the preceding vehicle's behavior but also other string members.

## 6.9. Decision making for automated vehicles in urban environments

**Participants:** Pierre de Beaucorps, Thomas Streubel, Anne Verroust-Blondet, Fawzi Nashashibi.

The development of automated vehicles in urban environments requires a robust sensing system followed by an adaptive situation assessment. This is the basis for smart decision making in the driving process without collisions or taking high risks. We address this aspect of automated driving in a project with the sensor developer VALEO. The focus is on complex urban traffic scenarios, e.g. intersections and roundabouts, including multiple road users.

In a first step, we developed a new multi-agent driving simulation as a tool to explore human behavior in relevant traffic scenarios. We conducted a study with 10 test persons driving in a scene with one dummy car to acquire data and understand the human decision process in risky situations. This data was used to retrieving speed profiles for the trajectory planning. The path planning was established with Bezier curves. Further, a robust decision making algorithm utilizes the trajectory planning coupled with a risk assessment. The latter is estimating the post-encroachment time (PET), which is the time between one vehicle leaving a collision zone in an intersection area and the other car entering this same zone. Based on this estimation a risk is assigned to every predetermined speed profile and the one with lowest acceptable risk is chosen to be send to the controller of the automated vehicle. The results showed better performance than the drivers in our study. The so equipped automated vehicle is integrated in our simulation environment and was presented to our project partners in several intersection and roundabout scenarios with a real driver in the same scene.

## 6.10. Transposition of autonomous vehicle architecture

**Participants:** Raoul de Charette, Pablo Marin Plaza, Fawzi Nashashibi.

With the development of autonomous vehicles, many software and hardware architectures exist in the world to handle perception, control, decision, planning. Studies were conducted to see how an alien software architecture could be transposed to our Cycabs platforms. Lightweight Communications and Marshalling has been implemented on our platforms to communicate fully with the Carlos 3 architecture, allowing the alien software pipeline to control fully our vehicle. Results and studies include stability of the communication, impact on the control quality, and planning comparison.

## 6.11. Fusion of Perception and V2P Communication Systems for Safety of Vulnerable Road Users

**Participants:** Pierre Merdrignac, Oyunchimeg Shagdar, Fawzi Nashashibi.

With cooperative intelligent transportation systems (C-ITS), vulnerable road users (VRU) safety can be enhanced by multiple means.

On one hand, perception systems are based on embedded sensors to protect VRUs. However, such systems may fail due to the sensors' visibility conditions and imprecision. On the other hand, Vehicle-to-Pedestrian (V2P) communication can contribute to the VRU safety by allowing vehicles and pedestrians to exchange information. This solution is, however, largely affected by the reliability of the exchanged information, which most generally is the GPS data. Since perception and communication have complementary features, we can expect that a fusion between these two approaches can be a solution to the VRU safety.

In this work, we proposed a cooperative system that combines the outputs of communication and perception. After introducing theoretical models of both individual approaches, we developed a probabilistic association between perception and V2P communication information by means of multi-hypothesis tracking (MHT).

Experimental studies were conducted to demonstrate the applicability of this approach in real-world environments. Our results showed that the cooperative VRU protection system can benefit of the redundancy coming from the perception and communication technologies both in line-of-sight (LOS) and non-LOS (NLOS) conditions. We established that the performances of this system are influenced by the classification performances of the perception system and by the accuracy of the GPS positioning transmitted by the communication system.

More detail can be fund in [24]

## 6.12. Study and Evaluation of Laser-based Perception and Light Communication for a Platoon of Autonomous Vehicles

**Participants:** Mohammad Abualhoul, Pierre Merdrignac, Oyunchimeg Shagdar, Fawzi Nashashibi.

Visible Light Communication (VLC) is a new emerging technology that is being proposed as a reliable and supportive choice for short range communications in ITS.

On the same context, Laser Range Finders (LRF) sensors are used for the vehicular environment perception. Compared to VLC, LRF can provide more coverage range and extended viewing angle.

To take the full advantages of both technologies features, we have studied and demonstrated the proposal of using VLC for information exchange among the platoon members and LRF for inter-vehicle distance estimation. A handover algorithm was proposed to manage the switching process for any failure occurrence by assessing LRF and VLC performance using three different metrics: LRF confidence value, vehicles angular orientation, and the VLC link latency.

The evaluation of the proposed system is verified using VLC prototype and Pro-SiVIC Simulator driving platoon of two autonomous vehicles over different curvature scenarios. Our results showed that the proposed combination are extending the VLC limitations and satisfying the platooning requirement. However, in the very sharp curvature, LRF was capable of driving the platoon except for the 90° curve scenario, the system experienced non-stable behavior due to the LRF area of interest limitation.

More detail can be fund in [27].

## 6.13. Solutions for Safety-Critical Communications in IVNs

**Participant:** Gérard Le Lann.

In 2016, we have followed a divide-and-conquer approach. Rather than considering medium-range omnidirectional communications, we have split the problem space in two sub-domains, longitudinal short-range SC communications and lateral short-range communications. Our research has been directed at MAC protocols, string-wide message dissemination based on longitudinal communications, and distributed agreement algorithms based on longitudinal and lateral communications. New results are:

- A rigorous characterization of what is meant by SC communications in IVNs: the space-time bounds acceptability (STBA) requirements, as follows:
  - $STBA_1$: a MAC protocol is acceptable if and only if the distance traveled in $\lambda$ time units by any vehicle involved in a SC scenario is an order of magnitude smaller than average vehicle size.

  - $STBA_2$: a string-wide message dissemination algorithm, or a string-wide distributed agreement algorithm, is acceptable if and only if the distance traveled in $\Delta$ time units by any vehicle involved in a SC scenario is smaller than average vehicle size.
- Specification of SWIFT (Synchronous Wireless Interference-Free Transmissions), a collision-free MAC protocol that solves the BCAD and the TBMA problems introduced in [48] (no solutions given in this publication), and that also achieves fast string-wide acknowledged message dissemination,
- Analytical formulae of worst-case upper bounds $\lambda$ and $\Delta$ achieved with SWIFT [36],
- Specification of Fast Distributed Agreement (FastDA), a problem that arises in IVNs in the presence of conflicting concurrent SC events (e.g., lane changes and brutal braking), under two instances, single-lane (longitudinal) agreement and multilane (lateral and longitudinal) agreement [37],
- Specifications of solutions to FastDA: the Eligo algorithm for the single-lane string-wide agreement (SLA), and the LHandshake protocol for the multilane agreement (MLA),
- Analytical formulae of worst-case upper bounds $\Delta_{SLA}$ and $\Delta_{MLA}$ achieved with Eligo and LHandshake, respectively [37],
- Verification that SWIFT, Eligo and LHandshake meet the STBA requirements.

It turns out that SWIFT, Eligo, and LHandshake outperform existing stochastic solutions.

## 6.14. Large scale simulation interfacing

**Participants:** Ahmed Soua, Jean-Marc Lasgouttes, Oyunchimeg Shagdar.

In order to efficiently design and validate a cooperative intelligent transportation system, a complete simulation environment handling both mobility and communication is required. We are interested here in a so-called system-level view, focusing on simulating all the components of the system (vehicle, infrastructure, management center, etc.) and its realities (roads, traffic conditions, risk of accidents, etc.). The objective is to validate the reference scenarios that take place on a geographic area where a large number of vehicles exchange messages using 802.11p protocol. This simulation tool is be done by coupling the SUMO microscopic simulator and the ns-3 network simulator thanks to the simulation platform iTETRIS.

We have focused in this part of the project on how to reduce the execution time of large scale simulations. To this end, we designed a new simulation technique called Restricted Simulation Zone which consists on defining a set of vehicles responsible of sending the message and an area of interest around them in which the vehicles receive the packets. In fact, the messages emitted by the vehicles located outside the interference zone are not useful for the simulation of the ego-vehicle, and therefore limiting the transmission area to a useful one reduces obviously the number of nodes involved in the transmission operation and thus reduces the processing time of messages. To corroborate the efficiency of our proposal, we compare it with an already existing simulation tool called COLOMBO. The simulation results have shown that our technique outperforms COLOMBO in terms of simulation execution time in the case of large scale simulations (when the number of vehicles exceeds 2400 nodes).

## 6.15. Belief propagation inference for traffic prediction

**Participant:** Jean-Marc Lasgouttes.

This work [50], in collaboration with Cyril Furtlehner (TAO, Inria), deals with real-time prediction of traffic conditions in a setting where the only available information is floating car data (FCD) sent by probe vehicles. The main focus is on finding a good way to encode some coarse information (typically whether traffic on a segment is fluid or congested), and to decode it in the form of real-time traffic reconstruction and prediction. Our approach relies in particular on the belief propagation algorithm.

The work about the theoretical aspects of encoding real valued variables into a binary Ising model has now been published [23].

Moreover, following an agreement signed with the city of Vienna (Austria) and the company SISTeMA ITS (Italy), we obtained access to large amounts of data. We are now working on assessing the performance of our techniques in real-world city networks.

## 6.16. Random Walks in Orthants

**Participant:** Guy Fayolle.

The Second Edition of the Book [45] *Random walks in the Quarter Plane*, prepared in collaboration with R. Iasnogorodski (St-Petersburg, Russia) and V. Malyshev (MGU, Moscow), is complete and now in the Springer Production Department. It will be published in the collection *Probability Theory and Stochastic Processes*. **Part II** of this second edition borrows specific case-studies from queuing theory, and enumerative combinatorics. Five chapters have been added, including examples and applications of the general theory to enumerative combinatorics. Among them:

- Explicit criterion for the finiteness of the group, both in the genus 0 and genus 1 cases.
- Chapter *Coupled-Queues* shows the first example of a queuing system analyzed by reduction to a BVP in the complex plane.
- Chapter *Joining the shorter-queue* analyzes a famous model, where maximal homogeneity conditions do not hold, hence leading to a system of functional equations.
- Chapter *Counting Lattice Walks* concerns the so-called *enumerative combinatorics*. When counting random walks with small steps, the nature (rational, algebraic or holonomic) of the generating functions can be found and a precise classification is given for the basic (up to symmetries) 79 possible walks.

## 6.17. Facing ADAS validation complexity with usage oriented testing

**Participant:** Guy Fayolle.

Validating Advanced Driver Assistance Systems (ADAS) is a strategic issue, since such systems are becoming increasingly widespread in the automotive field.

But, ADAS validation is a complex issue, particularly for camera based systems, because these functions maybe facing a very high number of situations that can be considered as infinite. Building at a low cost level a sufficiently detailed campaign is thus very difficult. The COVADEC project (type FUI/FEDER 15) aims to provide methods and techniques to deal with these problems. The test cases automatic generation relies on a *Model Based Testing (MBT)* approach. The tool used for MBT is the software MaTeLo (Markov Test Logic), developed by the company All4Tec. MaTeLo is an MBT tool, which makes it possible to build a model of the expected behaviour of the system under test and then to generate, from this model, a set of test cases suitable for particular needs. MaTeLo is based on Markov chains, and, for non-deterministic generation of test cases, uses the Monte Carlo methods. To cope with the inherent combinatorial explosion, we couple the graph generated by MaTeLo to an ad hoc *random scan Gibbs sampler (RSGS)*, which converges at geometric speed to the target distribution. Thanks to these test acceleration techniques, MaTeLo also makes it possible to obtain a maximal coverage of system validation by using a minimum number of test cases. As a consequence, the number of driving kilometers needed to validate an ADAS is reduced, see [40], [41].

## 6.18. Broadcast Transmission Networks with Buffering

**Participant:** Guy Fayolle.

In collaboration with P. Muhlethaler, we analyzed the so-called back-off technique of the IEEE 802.11 protocol in broadcast mode with waiting queues. In contrast to existing models, packets arriving when a station (or node) is in back-off state are not discarded, but are stored in a buffer of infinite capacity. As in previous studies, the key point of our analysis hinges on the assumption that the time on the channel is viewed as a random succession of transmission slots (whose duration corresponds to the length of a packet) and mini-slots during which the back-off of the station is decremented. These events occur independently, with given probabilities. The state of a node is represented by a two-dimensional Markov chain in discrete-time, formed by the back-off counter and the number of packets at the station. Two models are proposed both of which are shown to cope reasonably well with the physical principles of the protocol. Stability (ergodicity) conditions are obtained and interpreted in terms of maximum throughput. Several approximations related to these models are also discussed in [20].

# 7. Bilateral Contracts and Grants with Industry

## 7.1. Bilateral Contracts with Industry

**VALEO Group:** a very strong partnership is under reinforcement between VALEO and Inria. Several bilateral contracts were signed to conduct joint works on Driving Assistance, some of which VALEO is funding. This joint research includes:

- The PhD thesis of Pierre de Beaucorps and the post-doc of Thomas Streubel under the framework of VALEO project “Daring”
- *SMART* project: on the *Design and development of multisensor fusion system for road vehicles detection and tracking*. This project funds the internship of Alfredo Valle Bario.
- A CIFRE like PhD thesis is ongoing between VALEO and Inria (M. Maximilian JARITZ), dealing with multisensor processing and learning techniques for free navigable road detection.
- VALEO is currently a major financing partner of the “GAT” international Chaire/JointLab in which Inria is a partner. The other partners are: UC Berkeley, Shanghai Jiao-Tong University, EPFL, IFSTTAR, MPSA (Peugeot-Citroën) and SAFRAN.
- Technology transfer is also a major collaboration topic between RITS and VALEO as well as the development of a road automated prototype.
- Finally, Inria and VALEO are partners of the CAMPUS project (PIA french project) including SAFRAN, Invia and Gemalto. The aim of the project is the development of autonomous vehicles and the realization of two canonical uses-cases on highways and urban like environments.

**TATA Motors European Technical Centre (TMETC):** a new partnership was born in 2016 with the aim of developing a highly automated vehicle. Technology transfer from Inria to TATA Motors includes localization and mapping as well as control-command codes.

**Renault Group**: Collaboration between Renault and RITS re-started in 2016 and is expected to know a major growth in 2017. Three different research teams in Renault are now working separately with RITS on different topics.

A first concrete action was the beginning of a CIFRE PhD thesis funded by Renault and the French ANRT. The thesis deals with the accurate localization of an autonomous vehicle on a highway using mainly on-board low-cost perception sensors.

# 8. Partnerships and Cooperations

## 8.1. National Initiatives

### 8.1.1. ANR

#### 8.1.1.1. COCOVEA

Title: Coopération Conducteur-Véhicule Automatisé

Instrument: ANR

Duration: November 2013 - April 2017

Coordinator: Jean-Christophe Popieul (LAMIH - University of Valenciennes)

Partners: LAMIH, IFSTTAR, Inria, University of Caen, COMETE, PSA, CONTINENTAL, VALEO, AKKA Technologies, SPIROPS

Inria contact: Fawzi Nashashibi

Abstract: CoCoVeA project aims at demonstrating the need to integrate from the design of the system, the problem of interaction with the driver in resolving the problems of sharing the driving process and the degree of freedom, authority, level of automation, prioritizing information and managing the operation of the various systems. This approach requires the ability to know at any moment the state of the driver, the driving situation in which he finds himself, the operating limits of the various assistance systems and from these data, a decision regarding activation or not the arbitration system and the level of response.

#### 8.1.1.2. VALET

Title: Redistribution automatique d'une flotte de véhicules en partage et valet de parking

Instrument: ANR

Duration: January 2016 - December 2018

Coordinator: Fawzi Nashashibi

Partners: Inria, Ecole Centrale de Nantes (IRCCyN), AKKA Technologies

Inria contact: Fawzi Nashashibi

Abstract: The VALET project proposes a novel approach for solving car-sharing vehicles redistribution problem using vehicle platoons guided by professional drivers. An optimal routing algorithm is in charge of defining platoons drivers' routes to the parking areas where the followers are parked in a complete automated mode. The main idea of VALET is to retrieve vehicles parked randomly on the urban parking network by users. These parking spaces may be in electric charging stations, parking for car sharing vehicles or in regular parking places. Once the vehicles are collected and guided in a platooning mode, the objective is then to guide them to their allocated parking area or to their respective parking lots. Then each vehicle is assigned a parking place into which it has to park in an automated mode.

### 8.1.2. FUI

#### 8.1.2.1. Sinetic

Title: Système Intégré Numérique pour les Transports Intelligents Coopératifs

Instrument: FUI

Duration: December 2014 - May 2017

Coordinator: Thomas Nguyen (Oktal)

Partners: Oktal, ALL4TEC, CIVITEC, Dynalogic, Inria, EURECOM, Renault, Armines, IFSTTAR, VEDECOM

Inria contact: Jean-Marc Lasgouttes

Abstract: The purpose of the project SINETIC is to create a complete simulation environment for designing cooperative intelligent transport systems with two levels of granularity: the system level, integrating all the components of the system (vehicles, infrastructure management centers, etc.) and its realities (terrain, traffic, etc.) and the component-level, modeling the characteristics and behavior of the individual components (vehicles, sensors, communications and positioning systems, etc.) on limited geographical areas, but described in detail.

*8.1.2.2. PAC V2X*

Title: Perception augmentée par coopération véhicule avec l'infrastructure routière

Instrument: FUI

Duration: September 2016 - August 2019

Coordinator: SIGNATURE Group (SVMS)

Partners: DigiMobee, LOGIROAD, MABEN PRODUCTS, SANEF, SVMS, VICI, Inria, VEDECOM

Inria contact: Raoul de Charette

Abstract: The objective of the project is to integrate two technologies currently being deployed in order to significantly increase the time for an automated vehicle to evolve autonomously on European road networks. It is the integration of technologies for the detection of fixed and mobile objects such as radars, lidars, cameras ... etc. And local telecommunication technologies for the development of ad hoc local networks as used in cooperative systems.

### 8.1.3. Competitivity Clusters

RITS team is a very active partner in the competitivity clusters, especially MOV'EO and System@tic. We are involved in several technical committees like the DAS SUR of MOV'EO for example.
RITS is also the main Inria contributor in the VEDECOM institute (IEED). VEDECOM is financing the PhD theses of Mr. Fernando Garrido Carpio and Mr. Zayed Alsayed.

## 8.2. European Initiatives

### 8.2.1. FP7 & H2020 Projects

*8.2.1.1. CityMobil2*

Type: COOPERATION (TRANSPORTS)

Instrument: Large-scale integrating project

Objectif: NC

Duration: September 2012 - August 2016

Coordinator: University of Rome La Sapienza, CTL (Italy)

Partners: Inria (France), DLR (Germany), GEA Chanard (Switzerland), POLIS (Belgium), ERT (Belgium), EPFL (Switzerland),...(45 partners!)

Inria contact: Fawzi Nashashibi

Abstract: The CityMobil2 goal is to address and to remove three barriers to the deployment of automated road vehicles: the implementation framework, the legal framework and the unknown wider economic effect. CityMobil2 features 12 cities which will revise their mobility plans and adopt wherever they will prove effective automated transport systems. Then CityMobil2 will select the best 5 cases (among the 12 cities) to organize demonstrators. The project will procure two sets of automated vehicles and deliver them to the five most motivated cities for a 6 to 8 months demonstration in each city. CityMobil2 will establish a workgroup that will deliver a proposal for a European Directive to set a common legal framework to certify automated transport systems.

See also: http://www.citymobil2.eu/en/

*8.2.1.2. AutoNet2030*

Title: Co-operative Systems in Support of Networked Automated Driving by 2030

Objectif: NC

Duration: November 2013 - October 2016

Coordinator: Andras KOVACS – BROADBIT (Hungary)

Partners: BROADBIT (Hungary), BASELABS (Germany), CRF (Italy), Armines (France), VOLVO (Sueden), HITACHI EUROPE (France), EPFL (Switzerland), ICCS (Greece), TECHNISCHE UNIVERSITAET DRESDEN (Germany) (9 partners)

Inria contact: Fawzi Nashashibi

AutoNet2030 shall develop and test a co-operative automated driving technology, based on a decentralized decision-making strategy which is enabled by mutual information sharing among nearby vehicles. The project is aiming for a 2020-2030 deployment time horizon, taking into account the expected preceding introduction of co-operative communication systems and sensor based lane-keeping/cruise-control technologies. By taking this approach, a strategy can be worked out for the gradual introduction of fully automated driving systems, which makes the best use of the widespread existence of co-operative systems in the near-term and makes the deployment of fully automated driving systems beneficial for all drivers already from its initial stages.

See also: http://www.autonet2030.eu

*8.2.1.3. AUTOCITS*

Title: AUTOCITS Regulation Study for Interoperability in the Adoption of Autonomous Driving in European Urban Nodes

Program: CEF- TRANSPORT Atlantic corridor

Duration: November 2016 - December 2018

Coordinator: Indra Sistemas S.A. (Spain)

Partners: Indra Sistemas S.A. (Spain); Universidad Politécnica de Madrid (UPM), Spain; Dirección General de Tráfico (DGT), Spain; Inria (France); Instituto Pedro Nunes (IPN), Portugal; Autoridade Nacional de Segurança Rodoviária (ANSR), Portugal; Universidade de Coimbra (UC), Portugal.

Inria contact: Fawzi Nashashibi

Abstract: The aim of the Study is to contribute to the deployment of C-ITS in Europe by enhancing interoperability for autonomous vehicles as well as to boost the role of C-ITS as catalyst for the implementation of autonomous driving. Pilots will be implemented in 3 major Core Urban nodes (Paris, Madrid, Lisbon) located along the Core network Atlantic Corridor in 3 different Member States. The Action consists of Analysis and design, Pilots deployment and assessment, Dissemination and communication as well as Project Management and Coordination.

### *8.2.2. Collaborations with Major European Organizations*

RITS is member of the **euRobotics AISBL** and the Leader of “People transport” Topic. This makes from Inria one of the rare French robotics representatives at the European level. See also: http://www.eu-robotics.net/

RITS is a full partner of **VRA – Vehicle and Road Automation**, a support action funded by the European Union to create a collaboration network of experts and stakeholders working on deployment of automated vehicles and its related infrastructure. VRA project is considered as the cooperation interface between EC funded projects, international relations and national activities on the topic of vehicle and road automation. It is financed by the European Commission DG CONNECT and coordinated by ERTICO – ITS Europe. See also: http://vra-net.eu/

RITS is member of the Working Group on Automation: **iMobility**. This group has been created and is animated by ERTICO ITS Europe. The Automation Working Group was formed under the iMobility Forum, with the initial high level aims of exploring and promoting the potential of highly automated vehicles and applications and working towards the development of a roadmap for the deployment of automated systems.

# 8.3. International Initiatives

## *8.3.1. Inria International Partners*

### *8.3.1.1. International Academics Partners*

**NAIST – Japan**: RITS has a close cooperation with NAIST (Nara institute of Science and Technology), Japan since 2009. Based on this collaboration NAIST and Inria established the MoU agreement to accelerate and strengthen future research collaborations and the exchange of researchers and students. During the period February 2015 - March 2016 RITS hosted Sakriani Watiasri Sakti, assistant professor at NAIST.

**Seoul National University - S. Korea:** An International Cooperation Agreement has been signed between RITS team of Inria and the Vehicle Dynamics and Control Laboratory (VDCL) of Seoul National University (SNU). RITS and VDCL recognize the value of educational, cultural, and scientific exchanges between international research laboratories, and have determined that sufficient interest exists to establish an academic and research partnership for collaborative research and education in the area of future intelligent vehicle systems for sustainable safety and environment.

**International Chaire “Drive4U”:** Inria-RITS, Mines ParisTech, EPFL, Univ. of Berkeley (PATH Program) and Shanghai Jiao Tong Univ. (SJTU) are the academic partners of the international Chaire GAT, funded and supported by: VALEO Group, SAFRAN Group and MPSA Group (Peugeot-Citroën). A recent NDA has been signed recently. This Chaire will promote and fund academic activities related to Ground Automated Transportation and autonomous driving.

## *8.3.2. Participation in Other International Programs*

### *8.3.2.1. ICT-Asia*

**SIM-Cities**

Title: "Sustainable and Intelligent Mobility for Smart Cities"

International Partner (Institution - Laboratory - Researcher):

- Nanyang Technical University (NTU), School of Electrical and Electronic Engineering – Singapore. Prof. Dan Wei Wang

- National University of Singapore (NUS), Department of Mechanical Engineering – Singapore. Dr. Marcelo Ang

- Kumamotoo University - Japan. Intelligent Transportation Systems Lab, Graduate School of Science and Technology, Prof. James Hu / Prof. Ogata

- Shanghai Jiao-Tong University (SJTU), Department of Automation – China. Prof. Ming Yang

- Hanoi University of Science and Technology, International Center MICA Institute – Vietnam. Prof. Eric Castelli

- Inria, RITS Project-Team – France. Dr. Fawzi Nashashibi

- Inria, e-Motion/CHROMA Project-Team – France. Dr. Christian Laugier

- Ecole Centrale de Nantes, IRCCyN – France. Prof. Philippe Martinet

Duration: Jan. 2015 - May 2017

Start year: 2015

This project aims at conducting common research and development activities in the field of sustainable transportation and advanced mobility of people and goods in order to move in the direction of smart, clean and sustainable cities.

RITS and MICA lab have obtained from the Vietnamese Program 911 the financing of the joint PhD thesis of Dinh-Van Nguyen (co-directed by Eric Castelli from MICA lab and Fawzi Nashashibi).

*8.3.2.2. ECOS Nord – Venezuela*

**ECOS Nord**

Title: "Les Techniques de l'Information et de la Communication pour la Conception de Systèmes Avancés de Mobilité durable en Milieu Urbain."

International Partner (Institution - Laboratory - Researcher):

- Simon Bolivar University, Department of Mecatronics – Venezuela. Dr. Gerardo Fernandez

- Inria, RITS Project-Team – France. Dr. Fawzi Nashashibi

Duration: Jan. 2014 - Dec. 2017

Start year: 2014

The main objective of this project is to contribute scientifically and technically to the design of advanced sustainable mobility systems in urban areas, particularly in dense cities where mobility, comfort and safety needs are more important than in other types of cities. In this project, we will focus on the contribution of advanced systems of perception, communication and control for the realization of intelligent transport systems capable of gradually integrating into the urban landscape. These systems require the development of advanced dedicated urban infrastructures as well as the development and integration of on-board intelligence in individual vehicles or mass transport.

## 8.4. International Research Visitors

### *8.4.1. Visits of International Scientists*

**Sakriani Watiasri Sakti**, assistant professor at NAIST, from February 2015 until March 2016. A part of the work done during her stay has been published in [51].

**Aidos Ibrayev**, PhD student, from Kazakhstan.

**Pablo Marin Plaza**, PhD student, from Universidad Carlos III de Madrid, Spain.

*8.4.1.1. Internships*

**Rafael Colmenares Prieto, Juan Jose Larez Urdaneta, Daniel Sanchez Aranguren** from Simon Bolivar University, Venezuela.

**Aitor Gomez Torres, Alfredo Valle Barrio and Myriam Vaca Recalde** from Universidad Politécnica de Madrid, Spain.

**Jose Emilio Traver Becerra** from Universidad de Extremadura, Spain.

**Kenneth Martinez Torres** from Universidad del Turabo, Porto Rico.

**Alexis Meyer** from Télécom SudParis.

# 9. Dissemination

## 9.1. Promoting Scientific Activities

### *9.1.1. Scientific Events Organisation*

*9.1.1.1. Member of the Organizing Committees*

Fawzi Nashashibi: member of the steering committee of VENITS 2016 (2nd International Workshop on Vehicular Networking and Intelligent Transportation Systems), Sep. 2016, Valencia, Spain

### 9.1.2. Scientific Events Selection

#### 9.1.2.1. Member of the Conference Program Committees

Guy Fayolle: scientific program committee member of *The IEEE Computer Society's MASCOTS 2016 (Modelling, Analysis and Simulation of Computer and Telecommunication Systems)*, September 21-23, Imperial College, London, UK.

Vicente Milanés: international program committee member of IEEE International Conference on Intelligent Transportation Systems (ITSC 2016).

Fawzi Nashashibi: international program committee member of IEEE Intelligent Vehicles Symposium (IV 2016).

Fawzi Nashashibi: IPC for the 2016 IEEE Intelligent Transportation Systems Conference (ITSC'2016), 8th Workshop on Planning, Perception and Navigation for Intelligent Vehicles, Nov. 2016, Rio de Janeiro.

Fawzi Nashashibi: member of the Technical Program Committee of the 14th Int. Conference on Control, Automation, Robotics and Vision, Nov. 2016, Phuket.

Fawzi Nashashibi: member of the Technical Program Committee of the 2016 International Conference on Computer Science and Artificial Intelligence, Aug. 2016, Guilin.

Oyunchimeg Shagdar: program committee member of the IEEE International Conference on Advanced Information Networking and Applications (AINA 2016).

Ahmed Soua: technical program committee member of IEEE International Conference on Communications and of International Workshop on Vehicular Adhoc Networks for Smart Cities (IWVSC 2016).

Anne Verroust-Blondet: technical program committee member of MMEDIA 2016.

#### 9.1.2.2. Reviewer

Raoul de Charette: IEEE International Conference on Intelligent Transportation Systems (ITSC 2016).

Guy Fayolle: IEEE MASCOTS 2016 (Modelling, Analysis and Simulation of Computer and Telecommunication Systems) conference.

Jean-Marc Lasgouttes: IEEE MASCOTS 2016 (Modelling, Analysis and Simulation of Computer and Telecommunication Systems) conference.

Fawzi Nashashibi: International conference on Multidisciplinary in IT and Communication Science and Technologies 2016 (AIC-MITC), Transportation Research Board (TRB 2016), IEEE International Conference on Robotics and Automation (ICRA 2016), IEEE Intelligent Transportation Systems Conference (ITSC 2016), IEEE International Conference on Intelligent Robots and Systems (IROS 2016), International Conference on Advanced Robotics and Computer Vision (ICARCV 2016), Reconnaissance des Formes et Intelligence Artificielle (RFIA 2016).

Anne Verroust-Blondet: IEEE International Conference on Intelligent Transportation Systems (ITSC 2016).

### 9.1.3. Journal

#### 9.1.3.1. Member of the Editorial Boards

Guy Fayolle: associate editor of the journal *Markov Processes and Related Fields*

Vicente Milanés: editor-in-chief of Journal of Computer and Communications, associate Editor of Journal of Intelligent Transportation and Urban Planning.

Fawzi Nashashibi: associate editor of IEEE Transactions on Intelligent Vehicles, associate editor of the IEEE Transactions on Intelligent Transportation Systems, Editor of the Journal of Internet of Things (IoT) ISTE Editions (London).

Oyunchimeg Shagdar: associate editor of Wiley International Journal of Communication Systems.

*9.1.3.2. Reviewer - Reviewing Activities*

Raoul de Charette: *Journal of Computer and Communications*.

Guy Fayolle: *AAP, MPRF, PTRF, QUESTA, European Journal of Combinatorics, JSP, Physica A*.

Jean-Marc Lasgouttes: *Journal of Applied Probability, IEEE Transactions on Knowledge and Data Engineering*.

Pierre Merdrignac: *IEEE Trans. on Intelligent Transportation Systems*.

Fawzi Nashashibi: *IEEE Transactions on Intelligent Vehicles, IEEE Transactions on Intelligent Transportation Systems, IEEE Intelligent Transportation Systems Magazine*.

Ahmed Soua: *IEEE Communications Letters*.

Thomas Streubel: *IEEE Transactions on Intelligent Vehicles*.

Anne Verroust-Blondet: *Transactions on Pattern Analysis and Machine Intelligence*.

### *9.1.4. Invited Talks*

Raoul de Charette: "Perception research for Autonomous Vehicles", Sino-European Workshop on Information and Technology, Beijin, October 10-11 2016.

Guy Fayolle: "Random walks in the quarter-plane: explicit criterions for the finiteness of the associated group in the genus 1 case", Int. Conf. on Random Walks in Cones with Big Jumps, Tours, December 14-16 2016.

Fawzi Nashashibi:

1. Plenary keynote at the B.I.G. Forum (Big data Initiative of Gyeonggi). Invitation by the Geyonggi Province and Seoul National University, Oct. 19-20, Pangyo, Korea.
2. Keynote speaker at the Plenary session of the International Conference on Advanced Robotics and Computer Vision (ICARCV'2016), Nov. 15, Phuket, Thailand.
3. Keynote at the French ASPROM Workshop "'De la connectée à la voiture autonome : technologies, enjeux et applications"', Feb. 10-11, Paris, France.
4. Keynote at the "'Algorithms for HRI Workshop 2016"', July 21, Paris, France.

Anne Verroust-Blondet: "Sketch-based 3D model retrieval", Whitehead Lectures in Cognition, Computation and Culture, Goldsmiths, University of London, 24 May 2016.

### *9.1.5. Scientific Expertise*

Guy Fayolle is scientific advisor at the Robotics Laboratory of Mines ParisTech.

Jean-Marc Lasgouttes is member of the Conseil Académique of Université Paris-Saclay.

### *9.1.6. Research Administration*

Jean-Marc Lasgouttes is a member of the Comité Technique Inria.

Guy Fayolle is a member of the working group IFIP WG 7.3.

Fawzi Nashashibi is a member of the international Automated Highway Board Committee of the TRB (AHB30). He is a member of the Board of Governors of the VEDECOM Institute representing Inria and of the Board of Governors of MOV'EO Competitiveness cluster representing Inria.

Anne Verroust-Blondet is the scientific correspondent of the European affairs and of the International relations of Inria Paris. She is member of the COST-GTRI committee at Inria.

## 9.2. Teaching - Supervision - Juries

### 9.2.1. Teaching

Licence: Fawzi Nashashibi, “Programmation avancée”, 84h, L1, Université Paris-8 Saint-Denis, France.

Master: Jean-Marc Lasgouttes, “Analyse de données”, 54h, second year of Magistère de Finance (M1), University Paris 1 Panthéon Sorbonne, France.

Master: Fawzi Nashashibi, “Image synthesis and 3D Infographics”, 12h, M2, INT Télécom SudParis

Master: Fawzi Nashashibi, “Obstacle detection and Multisensor Fusion”, 4h, M2, INSA de Rouen.

Master: Fawzi Nashashibi, “Perception and Image processing for Mobile Autonomous Systems”, 12h, M2, University of Evry.

Master: Oyunchimeg Shagdar, “Nouvelles technologies de communication”, 32h, M2, University Versailles Saint-Quentin, France.

Master : Pierre Merdrignac, Introduction au traitement d’image, 12h (M1), Université Versailles Saint-Quentin en Yvelines, France.

Master: David González Bautista and Anne Verroust-Blondet, "Le véhicule autonome. Présentation des recherches de l’équipe-projet RITS",1.5 h, 2nd year, Ecole des Ponts ParisTech, France, Sept. 2016.

Doctorat: Jean-Marc Lasgouttes, “Analyse de données fonctionnelles”, 31.5h, Mastère Spécialisé “Expert en sciences des données”, INSA-Rouen, France

### 9.2.2. Supervision

PhD: Mohammad Abualhoul, “Visible light and radio communication for cooperative autonomous driving: applied to vehicle convoy”, Mines ParisTech, December 2016, supervisor: Fawzi Nashashibi, co-supervisor: Oyunchimeg Shagdar. (cf. [17])

PhD: Guillaume Trehard, “Gestion des intersections pour la conduite urbaine autonome”, Mines ParisTech, February 2016, supervisor: Fawzi Nashashibi.(cf. [18]).

PhD in progress : Zayed Al-Sayed, “Système de localisation redondant en environnement extérieur ouvert pour véhicule urbain automatique”, Télécom ParisTech, October 2014, supervisor: Anne Verroust-Blondet, co-supervisor: Guillaume Bresson.

PhD in progress : David González Bautista, “Contrôle coordonné et planification dynamique des trajectoires pour un système de transport cybernétique en milieu urbain instrumenté”, Mines ParisTech, January 2014, supervisor: Fawzi Nashashibi.

PhD in progress : Pierre de Beaucorps, “Autonomous vehicle: behavior prediction and Interaction with road users”, UPMC Paris, January 2016, supervisor: Anne Verroust-Blondet, co-supervisor: Fawzi Nashashibi.

PhD in progress : Fernando Garrido Carpio, “Optimal trajectory generation for autonomous vehicles in urban environments” , Mines ParisTech, November 2014, supervisor: Fawzi Nashashibi, co-supervisors: Vicente Milanés, Joshué Pérez.

PhD in progress : Carlos Flores, “Analysis and design of cooperative systems for trains of green cars”, Mines ParisTech, December 2015, supervisor: Fawzi Nashashibi, co-supervisor: Vicente Milanés.

PhD in progress : Francisco Navas, “Plug&Play control for highly non-linear systems: Stability analysis of autonomous vehicles”, Mines ParisTech, October 2015, supervisor: Fawzi Nashashibi, co-supervisor: Vicente Milanés.

PhD in progress : Dinh-Van Nguyen, "Wireless sensor networks for indoor mapping and accurate localization for low speed navigation in smart cities", Mines ParisTech, December 2015, supervisor: Fawzi Nashashibi, co-supervisor: Eric Castelli.

Starting PhD: Farouk Ghallabi, “Environment modeling and simultaneous localization of a mobile vehicle on motorways: a multi-sensor approach”, Mines ParisTech, October 2016, supervisor: Fawzi Nashashibi.

### *9.2.3. Juries*

Guy Fayolle was a jury member of the PhD thesis defense of Mohamed Hadded "Design and Optimization of Access Control Protocols in Vehicular Ad Hoc Networks (VANETs)", Télécom SudParis, 30 November 2016. Fawzi Nashashibi was a reviewer and examiner of the following PhD theses:

- Rémy Sohier – « Sensibilité artistique et création vidéoludique : Critique du jeu par le jeu et modèle ludographique ». Université Paris VIII Saint-Denis, 28 November 2016 – Reviewer

- Yiyuan Huang – « Méthode de création numérique et interactivité inconsciente entre philosophie de l’oeuvre et psychologie du participant. Ré-exploration de la peinture traditionnelle chinoise de manière numérique en utilisant l’installation artistique interactive ». Université de Paris VIII Saint-Denis, département Arts et Technologies de l’Image. 14 June 2016 – Reviewer

- Adela Sirbu – « Dynamic Machine Learning for Supervised and Unsupervised Classification”. Thèse en co-tutelle de l’Université BABES-BOLYAI, CLUJ-NAPOCA et de l’Université de Normandie délivrée par INSA Rouen. 6 June 2016 – Reviewer

- Carlos Fernandez-Lopez – «Road Scene Interpretation For Autonomous Navigation Fusing Stereo Vision and Digital Maps». Université de Alcalà (Spain). 23 September 2016 – Examiner

Anne Verroust-Blondet was:

- the external examiner of the PhD Examining Committee of Prashant Aparajeya’s PhD "Medialness-based shape invariant feature transformation", Goldsmidth, University of London (UK), 23 May 2016.

- a jury member of the PdD thesis defense of Arthur Truong "Analyse du contenu expressif des gestes corporels", Télécom SudParis, 21 September 2016.

## 9.3. Popularization

An article about YoGoKo (spinoff RITS) was published by bpifrance. *“YoGoKo joue la connectivité routière”*. Date: 09/02/2016.

“La Tribune” published an article about the Link&Go prototype developed by AKKA Technologies and Inria-Rits. *“Voiture autonome : la LINK & GO d’AKKA veut sortir des frontières”*, pp.72-73. Date: 29/06/2016. Journalist: Marie-Annick Depagneux.

Fawzi Nashashibi was interviewed in the “L’Auto-Journal” journal. Title: *“Les voitures autonomes sont là.”*. Date : 21/01-03/02 16. OJD : 105052, pp.30-32. Journalist: Brice Perrin.

Fawzi Nashashibi was interviewed in the “Usine Nouvelle” journal. Title: *“À la recherche du véhicule vraiment autonome”*. Date: 14/04/2016. Also: *“Le véhicule autonome fait avancer la simulation”*, pp. 48-49. Journalist: Frédéric Parisot.

Fawzi Nashashibi was interviewed in the “webcar center” (http://www.webcarcenter.com ). Title: *“Conduite autonome : les premières voitures sont là”*. Date: 10/02/2016. Journalist: Brice Perrin.

Fawzi Nashashibi was interviewed by “L’Automobile & L’Entreprise” (http://www.automobile-entreprise.com ). Journalist: Séverine Fontaine.

Fawzi Nashashibi was interviewed by “Télérama” magazine. Title: *“IA : c’est vraiment demain?”*. Date : 23/04-29/04 16. OJD : 578680. Journalists: Olivier Tesquet / Richard Sénéjoux.

Fawzi Nashashibi was interviewed by "Innovation Review". Title: *“Voitures autonomes : quel est le rôle du « deep learning » ?”*. Journalist: Thibault Lescuyer.

Fawzi Nashashibi was interviewed by “Les Echos” newspaper. Title: *“Google Car, le robot qui a remis la voiture autonome dans la course”*. Date: 02-03 Sept. 2016, pp.10-11. Journalist: Jacques Henno.

Fawzi Nashashibi was interviewed by "Science & Vie Special Edition - High Tech -". Title: *"Voiture connectée : la révolution cachée"*, pp. 78-83. Date: N 43/2016.

Fawzi Nashashibi was interviewed by "Industrie & Technologies". Title: *"Pourquoi et comment les véhicules autonomes vont devoir coopérer"*. Date: 11/10/2016. Journalist: Juliette Raynal. (https://www.industrie-techno.com/pourquoi-et-comment-les-vehicules-autonomes-vont-devoir-cooperer.46065 ).

Fawzi Nashashibi participated to a radio program on France Culture, La méthode scientifique, *"Jusqu'où ira l'autonomie des voitures ?"*, September 28, 2016.

Fawzi Nashashibi participated to a round table on *"Transports et énergies du futur"* for the event *Science en direct*, organized at the Cité des sciences et de l'industrie, Paris, October 8, 2016.

RITS team members participated to the making of a short movie dedicated to Teletoon Channel. Title/Serie: *"Culture Décode"*. Date: 09/12/2016. Journalist: Benjamin Brun (Tralalère: http://www.tralalere.com/ ).

# 10. Bibliography

## Major publications by the team in recent years


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