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Project-Team Imara

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THEME NUM

Activity Report

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2. Overall Objectives

2.1. Introduction

Keywords: *automated guided vehicle*, *environment*, *transportation systems*.

The focus of the project-team is to develop the technologies linked to Intelligent Transportation Systems (ITS) with the objective to improve the safety, the efficiency and the ease of use 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 "La Route Automatisée" 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 innovation. 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 optimisation of road transport system through a double approach:

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

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 performances of the vehicle (speed, throughput, 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 modelling and control of large transportation systems is also largely dependent on STIC. The objective there is to improve significantly the performances 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.

These two themes are largely dependent on the expertise of numerous project teams within INRIA and the past developments of IMARA's activities (or previous activities carried under the Praxitèle R&D team) have been largely done in cooperation with these teams. Conversely, these teams have often been fed by technical challenges brought by IMARA. We can mention for example mathematical models developed to forecast traffic, image processing techniques to localise precisely a mobile in its environment, new network protocols to insure connectivity between highly mobile units...

2.2. Highlights of the Year

- IMARA is now officially an INRIA Project Team since July 1st, 2008.
- *La Rochelle International Workshop*: to celebrate the European Mobility Week from 16 to 22 September 2008, the city of La Rochelle and INRIA presented two european projects in the field of alternative transportation solutions, CityMobil and CybersCars-2. INRIA organized an international workshop on "The automation for urban transport", and an *in situ* demonstration of the the latest innovative solutions for public transportation was organized.
- *ITS World Congress Joint Demonstration (NY - USA)*: A canonical demonstration was organized in the context of the 15th International World Congress on Intelligent Transportation systems.

INRIA and the SwRI (South-west Research Institute) developed a joint demonstration of intelligent communicant vehicles based on common software and hardware technologies from both institutions.

3. Scientific Foundations

3.1. Introduction

With the objective to improve significantly the performances of road transport through the sciences and technologies of information and communication, the research programme of IMARA focuses on the development, integration and demonstration of key technologies for:

- improving the vehicles through more and more assistance,
- managing the system though modelling and control,
- establishing efficient communications with vehicles.

3.2. Improving vehicle control

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.

3.2.1. Perception of the road environment

The perception and understanding of the environment is the key element which is needed whatever the application is (information to the driver, helping the driver or substitution of the driver). This research area continues therefore to be a focus point of our research. It starts with the processing of data from various sensors, the cameras being the most ubiquitous ones because of their large capabilities to apprehend the dynamic 3D environment. Obviously, fusion of data with various other sensors is also a focus of the research, since cameras alone cannot apprehend every possible complex situation. We already have large experience with Lidars (Ibeo) and we will now integrates also radar sensors in the fusion approach.

However, sensing the environment alone is not sufficient for the most complex road situation to help or replace the driver. We have to understand the situation, however complex it is. This is another key area of our research, which relies on various types of coding techniques to store the information about the environment and to interpret it. For example, we have coded the information using ontologies, allowing various subsystems of the vehicle or several vehicles to share information. We also store the environment information in normalized space-time representations to deal with the differences between road infrastructures measured in terms of their geometry and object entities.

We plan for example to use directed positional acyclic labelled graphs (DPAG's) to cope with very complex situations. Communications between the vehicles can also use this formalism. Using information from others, the vehicle can reduce the uncertainty of its local model and extend its coverage (see beyond what the vehicle in front sees, the one of the other lane sees).

3.2.2. Planning vehicle actions

The second level of our research on vehicle control concerns the planning of the actions to be taken. From the understanding of the situation, 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).

The idea of using communication to enhance map building or coordinating robots to achieve a task is not new. However, the vast majority of the works are done under constrains that are unrealistic for the urban environment scenario. Typical assumptions are perfect knowledge of the robots position and perfect communication (no delay, infinite throughput).

Even overlooking this, most of the algorithms do not match the application scenario where vehicles are expected to be part of a traffic flow, where sudden stops, forcing multiple encounters, revisiting places are not acceptable behaviours. The best teams in the world which took part of the DARPA Urban Challenge demonstrated that these problems have not yet been fully addressed.

3.2.3. Execution control

The third level of our research on vehicle control concerns the execution of the actions which have been elaborated at the two first levels. Obviously, this does not concern applications where only advice is given to the driver. Here, we have to execute in real-time a particular action or set of actions. The research we want to conduct is mostly centered on the software tools to implement such real-time actions in an accurate and safe way. This is a difficult problem, which is the focus of many industrial projects with the development of standards for interfaces and development procedures.

The project-team builds on its experience with the development of safety critical software for the operation of its cybercars to take part of these standards, in particular in the field of fail-safe software and redundant architectures.

3.3. Sensors and information processing

Keywords: *data fusion*, *image processing*, *laser*, *localization*, *magnetic devices*, *obstacle detection*, *radar*, *sensors*, *signal processing*, *stereovision*, *vision*.

Participants: Fawzi Nashashibi, Rodrigo Benenson, Yann Dumortier, André Ducrot, Gwennaelle Toulminet, Olivier Garcia, Laurent Bouraoui, Paulo Lopez Resende, Yoshio Mita.

3.3.1. Sensors and single-sensor information processing

The first step in the design of a control system are sensors and the information we want to extract from them, either for driver assistance or for fully automated guided vehicles. We put aside the proprioceptive sensors, which are rather well integrated. They give information on the host vehicle state, such as its velocity and the steering angle information. Thanks to sensor data processing, several objectives can be reached. The following topics are some applications validated or under development in our team:

- localization of the vehicle with respect to the infrastructure, i.e. lateral positioning on the road can be obtained by mean of vision (lane markings) or by mean of magnetic, optic or radar devices;
- detection and localization of the surrounding vehicles and determination of their behavior can be obtained by a mix of vision, laser or radar based data processing;

- detection of obstacles other than vehicles (pedestrians, animals objects on the road, etc.) that requires multisensor fusion techniques;
- simultaneous localization and mapping as well as mobile object tracking using a generic and robust laser based SLAMMOT algorithm.

Since INRIA is very involved in image processing, range imaging and multisensor fusion, IMARA emphasizes vision techniques, particularly stereo-vision, in relation with MIT, LITIS (Rouen) and Mines ParisTech.

3.3.1.1. Disparity Map Estimation

Participants: Yoshio Mita, Yann Dumortier, Laurent Bouraoui, André Ducrot, Fawzi Nashashibi, Gwennaelle Toulminet.

In a quite innovative approach presented in last year's report, we developed the Fly Algorithm, an evolutionary optimisation applied to stereovision and mobile robotics. Although successfully applied to real-time pedestrian detection using a vehicle mounted stereohead (see LOVe project), this technique couldn't be used for other robotics applications such as scene modeling, visual SLAM, etc. The need is for a dense 3D representation of the environment obtained with an appropriate precision and acceptable costs (computation time and resources).

Stereo vision is a reliable technique for obtaining a 3D scene representation through a pair of left and right images and it is effective for various tasks in road environments. The most important problem in stereo image processing is to find corresponding pixels from both images, leading to the so-called disparity estimation. Many autonomous vehicle navigation systems have adopted stereo vision techniques to construct disparity maps as a basic obstacle detection and avoidance mechanism.

We are working on a new approach for computing the disparity field by directly formulating the problem as a constrained optimization problem in which a convex objective function is minimized under convex constraints. These constraints arise from prior knowledge and the observed data. The minimization process is carried out over the feasibility set, which corresponds to the intersection of the constraint sets. The construction of convex property sets is based on the various properties of the field to be estimated. In most stereo vision applications, the disparity map should be smooth in homogeneous areas while keeping sharp edges. This can be achieved with the help of a suitable regularization constraint. We propose to use the Total Variation information as a regularization constraint, which avoids oscillations while preserving field discontinuities around object edges.

The algorithm we are developing to solve the estimation disparity problem has a block-iterative structure. This allows a wide range of constraints to be easily incorporated, possibly taking advantage of parallel computing architectures. This efficient algorithm allowed us to combine the Total Variation constraint with additional convex constraints so as to smooth homogeneous regions while preserving discontinuities.

3.3.2. Multi-sensor data fusion

Participants: Fawzi Nashashibi, Yann Dumortier, André Ducrot, Olivier Garcia, Laurent Bouraoui, François Charlot.

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.

IMARA has developed a framework for data acquisition, spatio-temporal localization and data sharing. Such system is based on a methodology for integrating measures from different sensors in a unique spatio-temporal frame provided by GPS receivers/WGS-84. Communicant entities, i.e. vehicles and roadsides exhibit and share their knowledge in a database using network access. Experimental validation of the framework was performed by sharing and combining raw sensor and perception data to improve a local model of the environment. Communication between entities is based on WiFi ad-hoc networking using the Optimal Link State Routing (OLSR) algorithm developed by the HIPERCOM research project at INRIA.

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's developments permitted the development of the basic hardware pieces that ensures the well functioning of the embedded architecture including perception sensors, communication devices and processing tools. The final architecture was relying on the *SensorHub* presented in last year's report. This year, we focused on the development of applications and demonstrators using this unique architecture. Thus, a canonical application was developed to demonstrate the ability of platooning using vehicle-to-vehicle communications to exchange vehicles absolute positions provided by respective GPS receivers.

This approach was presented at the ITS World Congress under the form of a cooperative driving demonstration with communicant vehicles. This demonstration was also the context of an international collaboration involving our team, the robotics center of ENSMP and the SwRI (see Section 7.1). A similar demonstration was presented in the context of the international workshop on "The automation for urban transport" that was held in the french city of La Rochelle. Here three Cycabs have shown platooning capacities and demonstrated the ability of supervising collision free insertion at an intersection. The Intersection Collision Warning System (ICWS) application was built here on top of CPF to warn a driver in case of potential accident. It relies on precise spatio-temporal localization of entities and objects to compute the Time To Collision (TTC) variables but also on a "Control Center" that collects the vehicles positions and sends back to them the appropriate instructions and speed profiles.

Finally, in a recent activity, we demonstrated an application of platooning in a public showcase in the town of Montbéliard. Two Cycabs were involved in a demonstration were vision-based and laser-based platooning capacities were demonstrated combined to dedicated controls.

Associated projects: Sharp, Icare, Complex.

3.4. Path planning and trajectory generation

Keywords: *command*, *control*, *dynamic behavior*, *generating trajectories*.

Participants: Fawzi Nashashibi, Rodrigo Benenson, Laurent Bouraoui, Paulo Lopez Resende.

We tackle two main topics: robot (or vehicle) control and path planning.

Control addresses the command system designed to execute at best the orders given by either the driver (assisted by the system) or the automated driving system (the co-pilot). The command system sends orders to the mechanical parts of the vehicles using all the information raised by the sensors or coming from path planner or an advanced co-pilot.

The real difficulty with this kind of control comes from the complexity of the dynamic behavior of the vehicle: response are highly non linear, particularly the response to forces of the tires on various soils. INRIA has a great expertise in these control problems and IMARA already demonstrated solutions for automatic driving of platoons of electrical cars. This research is still an active field. We recently designed and integrated a modular control architecture dedicated to the Cycabs. The system's low level is based on a DSPIC archietcture while the system management and core system integrates the Syndex system developed by the AOSTE project-team.

From the modeling point of view, we want to enhance the system concerning the speed, the variety of wheel-soil contact. The lateral control problem is also studied, particularly in view of drivers assistance. This is studied jointly with our LaRA partners (Robotics Center of ENSMP).

Path planning is another aspect of command systems dedicated to the generation of correct trajectories for an autonomous mobile robot (Cycabs) and for the autonomous mode of a vehicle. We currently work on a generic planner capable of finding secure trajectories for both robots and intelligent vehicles.

Associated projects: Sharp, Icare, Sosso, E-Motion.

3.5. Managing the system (via probabilistic modeling)

Keywords: *Markov process*, *exclusion process*, *probabilistic modeling*, *statistical physics*, *thermodynamic limit*, *traffic model*.

Participants: Guy Fayolle, Cyril Furtlehner, Jean-Marc Lasgouttes, Jennie Lioris.

The research on the management of the transportation system is a natural continuation of the research of the Preval team, which joined IMARA in 2007. For many years, the members of this team (and of its ancestor Meval) have been working on understanding random systems of various origins, mainly through the definition and solution of mathematical models. The traffic modelling field is very fertile in difficult problems, and it has been part of the activities of the members of Preval since the times of the Praxitèle project.

Following this tradition, the roadmap of the group is to pursue basic research on probabilistic modelling with a clear slant on applications related to LaRA activities. A particular effort is made to publicize our results among the traffic analysis community, and to implement our algorithms whenever it makes sense to use them in traffic management. Of course, as aforementioned, these activities in no way preclude the continuation of the methodological work achieved in the group for many years in various fields: random walks in Z_+^n ([2], [3], [6]), large deviations ([1], [8]) birth and death processes on trees, particle systems. The reader is therefore encouraged to read the recent activity reports for the Preval team for more details.

In practice, the group explores the links between large random systems and statistical physics, since this approach proves very powerful, both for macroscopic (fleet management [5]) and microscopic (car-level description of traffic, formation of jams) analysis. The general setting is mathematical modelling of large systems (mostly stochastic), without any a priori restriction: networks [4], random graphs or even objects coming from biology. When the size or the volume of those structures grows (this corresponds to the so-called thermodynamical limit), one aims at establishing a classification based on criteria of a twofold nature: quantitative (performance, throughput, etc) and qualitative (stability, asymptotic behavior, phase transition, complexity).

3.5.1. Exclusion processes

One of the simplest basic (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.

Most of these generalizations lead to models that are obviously difficult to solve and require upstream theoretical studies. Some of them models have already been investigated by members of the group, and they are part of wide ongoing research.

3.5.2. Message passing algorithms

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. Using some famous Ising models together with the Belief Propagation algorithm very popular in the computer science community, 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 properties of the Bethe approximation of Ising models

- how do the stability of the BP fixed points relate the the minima of the free energy?
- what is the effect of the various extensions to BP (fractional, tree-reweighted, region-based,...) of these fixed points?
- what is the behaviour of BP in the situation where the underlying data have many different statistical components, representing a variety of independent patterns?

3.6. Communications with vehicles

Participants: Thierry Ernst, Yacine Khaled, JinHyoeck Choi, Manabu Tsukada, Olivier Mehani.

As witnessed by standardization activities, conferences, research work and ITS projects across the world, Internet-based communication is now under the spotlight. Many of these projects are only considering the Internet for multimedia communications or together with the use of 3G cellular links. Few teams are investigating the full use of the Internet protocols for real vehicle-to-vehicle and vehicle-to-infrastructure communications, i.e. not only for multimedia, but also for navigation and safety purposes where critical data are exchanged over the air between vehicles. 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.

Here below is a more detailed description of our research plans for which we already have commitments.

3.6.1. Integration of MANET and NEMO

Mobile Adhoc Network (MANET) routing protocols such as OLSR are mostly used for vehicle-vehicle communications and network mobility (NEMO) support protocols to maintain the Internet access for vehicle-infrastructure communications. The necessary interaction between MANET and NEMO (MANEMO) brings a number of technical and scientific issues in terms of improved routing (routing optimization) and improved network accessibility (multihoming) because protocols have been specified independently from one another. In addition, we are investigating new routing protocol approaches adapted for the vehicular network characteristics such as geo-networking which is the favored approach of the automotive industry.

3.6.2. Multihoming in Nested Mobile Networks with Route Optimization

Network mobility has the particularity of allowing recursive mobility, i.e. where a mobile node is attached to another mobile node (e.g. a PDA is attached to the in-vehicle IP network). This is referred to as nested mobility and brings a number of research issues in terms of routing efficiency. Another issue under such mobility configurations is the availability of multiple paths to the Internet (still in the same example, the PDA has a 3G interface and the in-vehicle network has some dedicated access to the Internet) and its appropriate selection.

3.6.3. Service Discovery

Vehicles in a close vicinity need to discover what information can be made available to other vehicles (e.g. road traffic conditions, safety notification for collision avoidance). We are investigating both push and pull approaches and the ability of these mechanisms to scale to a large number of vehicules and services on offer.

3.6.4. Quality of Service (QoS)

The use of heterogeneous wireless technologies for vehicular networks incur varying deliverying delays or loss, though safety and some non-safety data must be transmitted in a bounded time frame. Also, these wireless technologies are often offered by various access network operators with different billing and filtering policies. We therefore need to investigate into mechanisms to provision network resources across access networks with different characteristics.

3.6.5. Security

Data exchanged between vehicles must be clearly authenticated and should guarantee the privacy of the vehicle user, as much from a location point of view as from a data content point of view. Mechanisms must be embedded into the communication architecture to prevent introduer to corrupt the system which could cause accidents and traffc congestion as a result of overloading the network or targeting a vehicle with forged or fake information.

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 who have strong mutual dependencies: driving assistance, cars available in self-service mode and fully automated vehicles (cybercars).

4.2. Driving assistance

Keywords: *Driving assistance*, *information*, *modeling*, *path planning*, *system management*.

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) path. 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

Keywords: *Transportation systems*, *information system*, *on demand*, *self-service*.

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. Cybercars

Keywords: *B2*, *Cybercars*.

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. IMARA 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 breaking and steering systems.

Regarding technical topics, several aspects of Cybercars have been developed at IMARA 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.

This application has a second feature, it can receive commands from an external source (Asynchronously 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, we have developed a R&D framework (Taxi) which takes control of the vehicle (Cycab and Yamaha) and also processes data such as gyro, GPS, cameras, wireless communications and so on. We compile C++ selected class, and we get a small footprint binary. We have demonstrated with this Taxi framework: 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 HIPERCOM team for setting and tuning OLSR, a dynamic routing protocol for vehicles communications (see Section 3.6). Our goal is to develop a vehicle dedicated communication software suite, running on a specialised hardware. It can be linked also with the Taxi Framework for getting data such GPS information's to help the routing algorithm.

5. New Results

5.1. Perception and autonomous navigation

Participants: Laurent Bouraoui, Olivier Garcia, François Charlot, Fawzi Nashashibi, Rodrigo Benenson, Paulo Resende.

For an autonomous navogation system to be efficient, it is necessary to have threee robust and relevant sub-systems: perception, planning and control. Very new results were achieved in perception this year with the development of a fast and reliable SLAMMOT system based on a single beam laser sensor. This system allows the environment scanning and modeling for the purpose of safe navigation on roads. The systems makes use of the built 3D model to generate a safe and optimized trajectory with repesct to some criteria. This path planner is another aspect of command systems dedicated to the generation of correct trajectories for both autonomous mobile robots (Cycabs) or traditional ground vehicles. Two canonical demonstrations were designed and first results exhibited.

5.1.1. Autonomous platooning and crossroads monitoring

Participants: Laurent Bouraoui, Olivier Garcia, François Charlot.

La Rochelle's international workshop on "The automation for urban transport" gave us the opportunity to test in situ the latest innovative solutions for public transportation. Our system consists in ensuring autonomous safe driving on a known track, platooning and crossroads monitoring. In this experiment, several Cycabs equipped with GPS devices and communication media are able to share their respective global positions, detect other Cycabs, form virtual or immaterial platonning and perform an intelligent monioring of the crossroads such that no accidents could occure between different Cycabs. This approach needs a refined localization thanks to map-matching techniques, a good perception and detection system and a well controlled synchronization with priority management.

5.1.2. A new co-pilot system for autonomous driving

Participants: Fawzi Nashashibi, Rodrigo Benenson, Paulo Resende.

We currently work on a generic planner capable of finding secure trajectories for both robots and intelligent vehicles. The framework of the european project “HAVE-IT” pushed us to adapt our existing partial motion planner (PMP) in order to adapt to the road driving context. The co-pilot to be designed for HAVE-IT is based on a two-levels architecture: a “strategy level” which decides the type of meneuver to be executed, and a “motion planning level” dedicated to find a collision-free trajectory that is feasible for the vehicle with respect to its kinematics capacities and non-holonomic constraints.

5.2. Managing the system (via probabilistic modeling)

5.2.1. Belief propagation inference with a prescribed fixed point

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes.

In the context of inference with expectation constraints, we analyze the approach based on the BP algorithm, which consists in encoding into a graph an a priori information composed of correlations or marginal probabilities of variables, and to use a message passing procedure to estimate the actual state from some extra information. We show that, when the coding is done usig Bethe approximation, the inference model is completely determined by the data which we encode, in terms of a prescribed fixed point. We also experiment other methods based on extension to Bethe free energy (joint work with Anne Auger, project-team TAO).

5.2.2. Effect of normalization in Belief propagation algorithm

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes.

We establish some general properties of BP are established concerning the effect of normalizing the messages, the relation between fixed points and their stability. In particular, we shed light on the respective effects of the factor graph topology through its spectrum on one end, and the effects of the encoded data by means of the spectral properties of a set of stochastic matrices attached to the data on the other end.

This is a work in progress.

5.2.3. Belief propagation and Bethe approximation for traffic prediction

Participants: Cyril Furtlehner, Arnaud de La Fortelle, Jean-Marc Lasgouttes.

This work [44] 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. Starting from the Ising model of statistical physics, we use a discretized space-time traffic description, on which we define and study an inference method based on the belief propagation (BP) algorithm. We propose a hybrid approach, by taking full advantage of the statistical nature of the information, in combination with a stochastic modeling of traffic patterns and a powerful message-passing inference algorithm. The idea is to encode into a graph the *a priori* information derived from historical data (marginal probabilities of pairs of variables), and to use BP to estimate the actual state from the latest FCD. Originally designed for bayesian inference on tree-like graphs, the BP algorithm has been widely used in a variety of inference problems (e.g. computer vision, coding theory, etc.), but to our knowledge it has not yet been applied in the context of traffic prediction.

These studies are done in particular in the perspective of the ANR project TRAVESTI, to begin in January 2009, which deals with traffic networks modelling.

5.2.4. Multi-speed exclusion processes

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes.

We have considered in [45] a one-dimensional stochastic reaction-diffusion generalizing the totally asymmetric simple exclusion process, and aiming at describing single lane roads with vehicles that can change speed. To each particle is associated a jump rate, and the particular dynamics that we choose (based on 3-sites patterns) ensures that clusters of occupied sites are of uniform jump rate. The basic assumption is that if a car gets in close contact to another one, it will adopt its rate. Conversely, if it arrives at a site not in contact with any other car, the new rate will be freely determined according to some random distribution. This models the acceleration or deceleration process in an admittedly crude manner. When this model is set on a circle or an infinite line, classical arguments allow to map it to a linear network of queues (a zero-range process in theoretical physics parlance) with exponential service times, but with a twist: the service rate remains constant during a busy period, but can change at renewal events.

This work has been continued this year, specifically by introducing a new type of zero-range processes with specific Markov non-reversibility and applying it to the computation of the fundamental diagram of road traffic.

5.2.5. Dynamical windings of random walks and exclusion models

Participants: Guy Fayolle, Cyril Furtlehner.

These last four years, several studies have been achieved about random walks evolving in the plane or even in $\mathbf{Z}^n$ and subjected to various local stochastic distortions (see activity reports of the Preval team 2004, 2005 and 2006).

In keeping with this general pattern, we pursued the work contained in reference [43]. The goal is to derive continuous limits of interacting one-dimensional diffusive systems, arising from stochastic distortions of discrete curves and involving various kinds of coding representations. These systems are essentially of a reaction-diffusion nature. In the non-reversible case, the invariant measure has generally a non Gibbs form. The corresponding steady-state regime is analyzed in detail with the help of a tagged particle and a state-graph cycle expansion of the probability currents. As a consequence, the constants appearing in Lotka-Volterra equations —which describe the fluid limits of stationary states— can be traced back directly at the discrete level to tagged particles cycles coefficients. Current fluctuations are also studied and the Lagrangian is obtained by an iterative scheme. The related Hamilton-Jacobi equation, which leads to the large deviation functional, is analyzed and solved in the reversible case, just for the sake of checking.

5.2.6. Statistical physics and hydrodynamic limits

Participants: Guy Fayolle, Cyril Furtlehner.

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

To attack this class of problems, in touch with many applications domains (e.g. biology, telecommunications, transportation systems), we started from *paradigmatic* elements, namely the discrete curves subjected to stochastic deformations, as those mentioned in section 5.2.5.

After convenient mappings, it appears that most problems can be set in terms of interacting exclusion processes, the ultimate goal being to derive hydrodynamic limits for these systems after proper scalings. We extend the key ideas of [42], where the basic ASEP system on the torus was analyzed. The usual sequence of empirical measures, converges in probability to a deterministic measure, which is the unique weak solution of a Cauchy problem.

The Gordian knot is the analysis of a family of differential operators in infinite dimension. Indeed, the values of functions at given points play here the role of usual variables, their number becoming infinite. The method presents some new theoretical features, involving promeasures (as introduced by Bourbaki), variational calculus and functional integration. In the ongoing work [37], these arguments are applied to various multi-type exclusion systems, including the famous ABC model. Also, in the course of the study, several fascinating multi-scale problems emerge quite naturally, bringing to light quite natural connections with the so-called *renormalization* in theoretical physics.

5.2.7. Convergence of moments in the almost sure central Limit theorem for multivariate martingales

Participant: Guy Fayolle.

Let (ξ_n) be a sequence of i.i.d. random variables, with $\mathbb{E}[\xi_n] = 0$ and $\mathbb{E}[\xi_n^2] = \sigma^2$. Let $\Sigma_n = \xi_1 + \cdots + \xi_n$. The almost sure central limit theorem (ASCLT) asserts that, for any bounded continuous function h,

$$\lim_{n\to\infty} \frac{1}{\log n} \sum_{k=1}^{n} \frac{1}{k} h\left(\frac{\Sigma_k}{\sqrt{k}}\right) = \int_{\mathbb{R}} h(x)dG(x), \quad \text{a.s.},$$

where G is a gaussian measure $\mathcal{N}(0, \sigma^2)$. This theorem also holds for martingales.

In a joint work [35], which started in 2006 in collaboration with Bernard Bercu (University Bordeaux 1) and Peggy Cénac (University Dijon), we investigate the almost sure asymptotic properties of vector martingale transforms. Assuming some appropriate regularity conditions both on the increasing process and on the moments of the martingale, we prove that normalized moments of any even order converge in the almost sure cental limit theorem for martingales. A conjecture about almost sure upper bounds under wider hypotheses is formulated. The theoretical results are supported by examples borrowed from statistical applications, including linear autoregressive models and branching processes with immigration, for which new asymptotic properties are established on estimation and prediction errors.

5.2.8. Evaluation of collective taxi systems by event-driven simulation

Participants: Jennie Lioris, Arnaud de La Fortelle.

The purpose of this research is to introduce the new mode of transportation “Collective Taxis”, which will offer a high quality of service at a cost affordable by almost everyone. This will be achieved by using well optimised itineraries in order to minimise detours whilst retaining the versatility to accept roadside clients in addition to those who have booked in advance.

As we are dealing with an extremely complex structure, it is virtually impossible to write a mathematical model at present. Therefore we have to observe and learn the behaviour of the system by using simulations. This will enable us to study and analyse the results in order to optimise the system performance at minimal cost or risk.

We have just completed conception and implementation of the system and are currently considering how best to use the simulation results to produce statistics for learning the system. Simultaneously we are studying the various control algorithms which we hope to apply in order to examine the system behaviour.

5.3. Communications with vehicles

Short term objectives in this domain is the development of routing protocols which are fast enough to allow cooperative manoeuvres between cybercars, the specification of IPv6 mobility features that will improve the known routing inefficiencies and the performance analysis of existing routing and path selection mechanisms. New standards for vehicle to vehicle communications are also expected from this activity through our involvment in standardization bodies (ISO, IETF and ETSI).

Longer term actitivies include studying novel routing mechanisms such as a geographic addressing and routing (geonetworking), specifying mechanisms that will allow to guarantee a minimum quality of service while a vehicle is moving across heterogeneous access networks, and the analysis of security threats on the vehicular networks. All of these are parts of our objective to provide a packet-switched communication architecture suitable for the vehicular networks needs.

5.3.1. New Communications Architectures for ITS

Participants: Thierry Ernst, Olivier Mehani, Manabu Tsukada, Yacine Khaled.

The purpose of this research is to investigate the use of IPv6 protocols for ITS communication architectures. IPv6 is assumed as the de facto version of the Internet Protocol where Internet-based communications are necessary in vehicular networks. This is motivated by the need from the ITS industry for an extended address space and the enhanced mechanisms that only IPv6 provides. The use of IP (whatever its version) is still questioned by the automotive industry for time-critical safety applications. IP applicability must thus be investigated by conducting performance evaluation of the communication system.

This year we have significantly pushed for integration of IPv6 features and contributed significant text into ITS communication architecture standards specifications, particularly at ISO TC204 WG16 [32] and COMeSafety (European project proposing a reference ITS communication architecture for European projects) [33]. We have also analyzed the ns-3 simulator's ability to evaluate the performance of our propositions and we have prepared an evaluation strategy to collect data and analyze them when performing live experiments on our vehicles. IETF standardization activities as described in [34], [39], [38], [36] are also related to this topic.

5.3.2. Geographic routing and addressing

Participants: Thierry Ernst, Yacine Khaled, JinHyeock Choi.

This topic has been launched in October 2007 and is driving an important part of IMARA's resources given our commitment on the GeoNet project which started in February 2008. The purpose of this research is to research into routing protocols adapted to vehicular networks where a certain information, particularly safety information, must be delivered to all or a set of vehicles located in a specific geographic area with minimum network overhead and minimum latency. We are investigating how such feature could be provided at the IP level over several networks and operators. This topic is currently studied as part of a doctoral thesis which started in December 2007. We also published [19] on this topic.

5.3.3. Maintaining Internet Connectivity

Participants: Thierry Ernst, Olivier Mehani.

Vehicles are moving and are thus changing their point of attachment to the Internet. While moving, the Internet connectivity must be maintained and session continuity must be ensured. Areas of investigation include:

- Mobility support for vehicle-infrastructure communications or maintaining Internet connectivity while on the move (e.g. NEMO)
- Addressing for vehicular networks: some vehicle may remain not connected to the Internet for a long time so the addressing format must be designed taking this into account.
- Transport protocols adapted to mobile environments.
- Study of security threats in mobile environments.

This topic is currently studied as part of a doctoral thesis which started in December 2007. Our current results on transport protocols have been published in [24]. Results published in [12] (multihoming) and [28] (access control and security) are also related.

5.3.4. Integration of NEMO and MANET

Participants: Thierry Ernst, Manabu Tsukada.

Mobile Adhoc Network (MANET) routing protocols and network mobility (NEMO) support protocols are used in vehicular communications; MANET for vehicle-vehicle communications, and NEMO to maintain the Internet access for vehicle-infrastructure communications. The necessary interaction between MANET and NEMO (MANEMO) brings a number of benefits in terms of improved routing (routing optimization) and improved network accessibility (multihoming). However, protocols have been specified independently from one another and their interaction brings a number of technical and scientific issues. Areas of investigation include:

- Routing protocols in infrastructure-less networks for direct or multihop vehicle-vehicle communications: ad-hoc routing protocols (MANET, e.g. OLSR) and geographic routing;

- Selection of the appropriate path when multiple access technologies are available (multihoming) and when both multi-hop vehicle-vehicle or direct vehicle-infrastructure communications are possible;
- Routing optimization: mobility management usually requires routing through some mobility support server in the Internet, which could lead to routing inefficiencies;
- Network mobility has the particularity of allowing recursive mobility, i.e. where a mobile node is attached to another mobile node (e.g. a PDA is attached to the in-vehicle IP network). This is referred to as *nested mobility* and brings a number of research issues in terms of routing efficiency.

This topic is currently studied as part of a doctoral thesis which started in September 2007. Our current results have been published in [27]. IETF standardization activities as specified in [39], [36], [38] are also related to this topic.

6. Contracts and Grants with Industry

6.1. Introduction

The IMARA project is mainly funded by the numerous contracts obtained the past years and which show the guidelines of its works.

6.2. Anemone

Anemone is a small European project (STREP) aiming at deploying an IPv6 mobility testbed at several complementary sites providing third parties users support of mobile devices and enhanced services by integrating cutting edge IPv6 mobility and multihoming initiatives together with the majority of current and future wireless access technologies. IMARA is associated with the ARMOR project-team in Rennes and is mostly committed to conduct research on network mobility and multihoming for which we hired a PhD student. As such, we have realized an experiment in Rennes in December 2007 involving two of our vehicles in order to evaluate the performance of an optimized routing solution between the two vehicles using a combination of NEMO and MANET technologies, integrated in the same hardware running Linux. We are also acting as a liaison between the Anemone and CVIS projects and as such, we conducted a joint demonstration during the ICT event in Lyon, November 2008. The project concluded in November 2008. [26] was published in order to advertise the ITS capabilities of the testbed.

Contractor: EU // Project duration: 2 years (2006-2008) // R&D grant: euros 100 000.

6.3. Citymobil

The objective of the CityMobil project is to focus on a number of cities in Europe and by careful study of their requirements design, evaluate and test the new approaches at three sites (Heathrow, Rome and Castellón). At the end of the project, we will have a better understanding of the capabilities of the new technologies and of what the gains to be expected in various city-situations could be and we will have proposals for certification of advanced transport systems on a European level. We will also have the tools to disseminate the results widely on the European level and therefore bring to the cities proven solutions to their problems while becoming, as was stated "a global leader in the development of a knowledge-based transport sector".

Contractor: EU // Project duration: 2 years (2006-2008) // R&D grant: euros 100 000.

6.4. CVIS

CVIS is a large European project (IP) specifying an IPv6-based communication architecture and a set of applications for vehicle-roadside and vehicle-Internet communications. The work is based on CALM standard from ISO. CVIS is now developing a multi-channel mobile router capable of maintaining connectivity with the roadside and the Internet through a number of wireless communications media (802.11a/b/g, 802.11p, 3G). INRIA is bringing the necessary IPv6 insight into this project and is leading all aspects related to IPv6 (specification, dissemination). In charge of defining the IPv6 communication architecture, INRIA contributed to the specification and validation work, and we spent a lot of time informing the partners about the impact of IPv6 on their work and investigating the interoperability with legacy systems deployed at test sites. INRIA providing IPv6 training to CVIS partners and advised partners involved at test sites on IPv6 issues. As part of this project, INRIA contributed to european and worldwide effort in ITS communication architecture standardization (ISO TC204 WG16 [32], ETSI TC ITS, COMeSafety [33]).

Contractor: EU // Project duration: 4 years (2006-2010) // R&D grant: euros 266 000.

6.5. Cybercars 2

Cybercars 2 goal is to further improve the technologies of the CTS in order to make them into a truly efficient urban transport system of the future. The existing systems can offer a good alternative to the private cars but only if the transportation demand is not very high. To attain capacities of the same order of magnitude as private cars we have to improve our technologies by one order of magnitude since present day cybercars cannot transport much more than a few hundreds of passengers per hour on a single lane (compared to 2,000 with private cars and more than 10,000 with trams).

Contractor: EU // Project duration: 3 years (2006-2008) // R&D grant: euros 484 000.

6.6. LOVe

LOVe is an initiative to gather players around the automotive electronics for detection and protection of vulnerable users (pedestrians, cyclists, etc.). This is part of the Num@tec cluster and of the French System@tic *pôle de compétitivité*.

Contractor: France // Project duration: 3 years (2006-2009) // R&D grant: euros 151 000.

6.7. Tiny6 (STIC-Asie)

Led by ENST Bretagne, Tiny6 is a STIC-Asie project with Indian, Korean, Chinese, Taiwanese and French labs aiming at exchanging knowledge on IPv6 wireless sensor networks. The kick-off was held in September 2007 in Paris. Our main interest is to develop our know-how in order to define wireless IPv6 sensors that could be developed for ITS, and to establish links leading to stronger cooperation with Asian partners.

6.8. Cristal

The French project Cristal is led by Lohr industrie and aims at building an advanced vehicle (3-8 people) that could move in platoons. This initiative is supported by the *pôle de compétitivité* “Véhicules du futur”, in the eastern part of France.

Contractor: FCE // Project duration: 3 years (2007-2010) // R&D grant: euros 100 000.

6.9. DIVAS

The French project DIVAS is a consortium of industry partners, research labs and road authorities. Its goal is to develop an architecture for road-vehicles cooperation and to build demonstration applications to validate the design. This initiative is supported by the *pôle de compétitivité* MOV’EO. There is also a cooperation with the US inside the project DIVAS America.

Contractor: ANR // Project duration: 3 years (2007-2010) // R&D grant: euros 95 000.

6.10. AROS

AROS is a consortium dedicated to the design and validation of a new advanced prototyping software aiming at decreasing seriously the development cycle of embedded distributed applications, particularly in the scope of automotive products. Partners are Mines Paris, VALEO and Intempora.

Contractor: ANR // Project duration: 3 years (2008-2011) // R&D grant: euros 142 000.

6.11. HAVE-IT

HAVE-IT aims at the long-term vision of highly automated driving. Within this proposal important intermediate steps towards highly automated driving will be developed, validated and demonstrated. First by optimizing the task repartition between driver and co-pilot system (ADAS) in the joint system. Then by further developing and implementing the failure tolerant, safe vehicle architecture including advanced redundancy management (from the SPARC predecessor project) to suit the needs of highly automated vehicle applications and to arrive at higher system availability and reliability. Finally by developing and validating next generation ADAS directed towards higher level of automation compared to the current state of the art.

Contractor: EU // Project duration: 3.5 years (2008-2011) // R&D grant: euros 443 000.

6.12. GeoNet

The GeoNet project has been set up in order to combine IPv6 and geographic routing in the communication architecture specified by the Car-to-Car Communication Consortium (C2C-CC). This combination is needed in order to guarantee interoperability between ITS communication architectures and Internet-based communications. The objective of the project is to specify the architecture where C2C-CC's geographic routing would be combined with ISO's CALM IPv6 features (NEMO, etc.). The project is currently producing a reference specification of a geographic addressing and routing protocol with support for IPv6 to be used to deliver safety messages between cars but also between cars and the roadside infrastructure within a designated destination area.

INRIA (Arnaud de La Fortelle and Thierry Ernst) is coordinator of this proposal.

Contractor: EU // Project duration: 2 years (2009-2010) // R&D grant: euros 500 000.

6.13. MobiSeND

This ANR project aims at securing neighbor discovery in wireless mobile environments. Neighbor discovery is an essential protocol part of the IPv6 protocol suite and is used in our ITS communication architecture. This protocole has proven to be unsecured in wireless communications. The role of IMARA is to participate to the State of the Art analysis, to the implementation and more importantly to the live demonstation on real vehicles (IMARA's C3). The benefit for the team is to develop our know-how on security issues and to study ITS-specific security threat at the network layer.

Contractor: ANR // Project duration: 2 years (2008-2010).

6.14. Intersafe-2

The INTERSAFE-2 project aims at developing and demonstrating a Cooperative Intersection Safety System (CISS) that is able to significantly reduce injuries and fatal accidents at intersections. The novel CISS combines warning and intervention functions demonstrated on three vehicles: two passenger cars and one heavy goods vehicle. Furthermore, a simulator is used to perform additional R&D work. These functions are based on novel cooperative scenario interpretation and risk assessment algorithms.

Contractor: EU // Project duration: 3 years (2008-2011) // R&D grant: euros 317 000.

6.15. Merit

MERIT (Modules Electroniques Robotisés Intelligents pour les Transports: Smart Robotized Electronic Modules for Transport) is a French project aiming at the development and industrialization of electronic modules for driving assistance. The main focus is for ageing population. Afterward, the same modules could be used for helping beginners or handicaped people, to automate public transport or for general driving assistance.

Contractor: ANR // Project duration: 2 years (2008-2009) // R&D grant: euros 40 000.

7. Other Grants and Activities

7.1. International relations

We are cooperating with a number of labs worldwide without contract commitment.

SwRI: in 2007, INRIA signed a collaboration agreement with the Southwest Research Institute (San Antonio, Texas, USA) for the joint development of autonomous vehicle technologies, focusing on the areas of perception, intelligence, command and control, communications, platforms and safety. SwRI is one of the oldest and largest nonprofit applied research and development organizations in the U.S. The partnership will conduct joint research and exchange intellectual property to foster rapid technology and system advancements in vehicle autonomy.

Keio University (Japan): IMARA has established links with Jun Murai Lab at Keio University in Japan since 2005, which led Thierry Ernst to join IMARA in 2006. Since then, we are working with Keio University and other labs in Japan and in France grouped into the Nautilus6 project which is working on IPv6 mobility enhanced mechanisms allowing continuous access to the Internet while on the move. From this cooperation, we were able to hire a PhD student who completed his MSc at Keio University. In addition, three labs from Keio University with different backgrounds (automatic vehicles, electric vehicles and Internet communications) have joined forces into the so-called co-Mobility project aiming at developing the vehicle of the future. The intersection between Keio University's activities on this project and IMARA is a tremendous set of common research topics and as such we have been invited to a Co-Mobility workshop in Japan in January.

University of Tokyo (Japan): During his 1-year stay within IMARA Dr. Yoshio Mita's (associate professor at Tokyo University) was successful into organizing a private workshop between University of Tokyo and IMARA. It was held in July and gathered 10 researchers from Japan. From this workshop a number of new collaboration items were identified, including on the communication research topic in which there was not previous cooperation with University of Tokyo. As a result from this, we participated to the internal "Associated Team" program call without success and to the Japanese-French AYAME program call to work on green transportation ITS communication technologies. The former was accepted, so we are likely to enforce our cooperation with University of Tokyo in 2009.

NICTA (Australia): After first contacts established in 2007, a PhD student started his work on a join PhD program between NICTA and IMARA. This student is currently working in Australia. We also participated to the internal "Associated Team" program call, without success. Our commitment on this joint PhD supervision guarantees an outstanding cooperation with NICTA.

University of Murcia (Spain): After a first contact established at the Mobile IST Summit in summer 2007 with Antonio F. Gómez Skarmeta, a PhD student from University of Murcia (José Santa Lozano) was hosted by IMARA for 3 months. He studied our communication architectures and realized some performance evaluation of our communication system using our in-vehicle testbed. The evaluation tools developed during this work will be used again to evaluate forthcoming results on geographic networking.

We also maintain longstanding bilateral relations with the following centers.

- University of Moscow (V. Malyshev);
- University of Saint-Petersburg (R. Iasnogorodski);
- IPPI, Dobrushin's Laboratory, Academy of sciences, Moscow (A. Rybko);
- Imperial College (E. Gelenbe);
- University of Oxford (J. Martin);
- several teams in USA (Berkeley, Columbia, Monterey, AT&T).

7.2. National relations

We collaborate more or less tightly with the following french universities and research centers.

- Mines ParisTech (Robotics Lab): very strong collaboration through the Joint Research Unit LaRA;
- University of Bordeaux 1, Institut de Mathématiques de Bordeaux (B. Bercu);
- University of Paris 11, LPTMS (A. Comtet et S. Majumdar);
- France Télécom R&D, DAC/OAT (J. Roberts);
- ENS Ulm (P. Brémaud, B. Derrida, J.-F. Le Gall);
- ENSAE (P. Doukhan);
- CEA (C. Godrèche et K. Mallick);
- Télécom Bretagne (Jean-Marie Bonnin, Laurent Toutain, Nicolas Montavont);
- Université de Compiègne (Bertrand Ducourthial);

8. Dissemination

8.1. Standardization

We are actively involved in the international standardization process in the communication area.

IETF (Internet Engineering Task Force): Thierry Ernst has served as Working Group chair in two Working Groups (NEMO standing for "Network Mobility" and MonAmi6 standing for "Mobile Nodes and Multiple Interfaces in IPv6") he has contributed to set up while working at Keio University (in 2002 and 2005, respectively) until their closure in December 2007. He is author of a few RFCs [41], [40], [46] and drafts [34], [39], [38], [36].

ISO TC204 WG16: Thierry Ernst who was contributing as an observer to the ISO activities within the Technical Committee Working Group 16 (TC204 WG16) since 2002 has become in spring 2007 an official delegate representing French interests (AFNOR) in that group. TC204 WG16 is specifying the CALM communication architecture based on IPv6 and NEMO and currently implemented by the CVIS European project in which we are also involved. He particularly contributed to ISO 21210 "CALM: IPv6 Networking" [32].

C2C-CC: INRIA (for IMARA: Thierry Ernst, Arnaud de La Fortelle, Samer Ammoun, Yacine Khaled) have joined the Car-to-Car Communication Consortium (C2C-CC) which is a European association of car manufacturers and electronic equipment suppliers. There are designing a communication architecture mainly for vehicle-vehicle safety communications. We are bringing our expertise on IPv6 communications.

COMeSafety: COMeSafety is a European forum whose aim is to ensure that the various European projects (CVIS, SafeSpot, Coopers) and the C2C-CC, all working on vehicular communications, will provide interoperable solutions. We are bringing our expertise on IPv6 communications. Thierry Ernst contributed one chapter and other sections to the European ITS Architecture document [33].

ETSI TC ITS: A technical committee for ITS has started this year at ETSI, and IMARA is also getting involved, ensuring the link with the GeoNet and CVIS European projects and also with IETF and ISO on aspects related to geonetworking and IPv6.

8.2. Animation

As part of our work in vehicular communications we served as session chairs, in technical committees, in panels of a number of events, and we also proposed sessions held in a number of ITS conferences, including the ITS in Europe conference. In addition to TPCs we participated actively, we also provided reviews for various journals and conferences.

Thierry Ernst is in charge of the thematic group LaRA-COM within the LaRA joint research unit with Ecole des Mines de Paris and is working on IPv6-based communications and routing applied to ITS. This year he participated to various panel sessions, gave keynotes speeches at several conferences, served in a number of TPCs (ITST, WEEDEV, IEEE WiVeC, WNS2, CFIP, IEEE LCN ON-MOVE, WITS), provided reviews for various journal and conference papers (Elsevier COMCOM, IEEE TMC, IEEE TVT, IPMMA, ETRI, and Annales desTelecom) and served in 3 PhD defence committees. He is involved in several european and national projects related to IPv6 (CVIS, ANEMONE, GeoNet, MobiSEND) that he largely contributed to set up. His IPv6 expertise was requested in many occasions in standardization bodies and forums (IETF, ISO, Car-to-Car Communication Consortium, COMeSafety, ETSI, European Commission's action plan on IPv6). As part of his dissemination activities related to IPv6, he is in charge of the IPv6 Task Force France since September 2006 and is secretary of the G6 association since July 2007. As such, he was interviewed by several journalists and also by the CGTI under the responsability of the ministry of economy, industry and employment. He also organized two networking sessions on IPv6 during the European ICT event in Lyon, one related to IPv6 deployment in ITS architectures, and one related to IPv6 dissemination. Thierry Ernst also entertains international relations with several labs, and particularly with Keio Univeristy, University of Tokyo, and the WIDE organization in Japan (he is a WIDE member).

Guy Fayolle is an editor of the journal *Markov Processes and Related Fields*. He is also member of the working group *IFIP WG 7.3*, which has about a 150 elected persons from scientific communities interested in various aspect of system modeling and performance evaluation. He accepted the invitation (july 2008) of Pr. Clancey to become a reviewer for *Mathematical Reviews*. He has organized, together with Jean-Marc Lasgouttes and Erol Gelenbe (Imperial College, London) the symposium *model35* on *Perspectives in Modeling and Performance Analysis of Computer Systems and Networks*, which took place at INRIA Paris-Rocquencourt in April 2008. He has been invited speaker at the international conference *Interacting Particle Systems and Percolation* [IHP (Institut Henri Poincaré), Paris, Oct. 27–Nov. 3], where he gave a talk *Hydrodynamic limit of some multi-type exclusion processes via functional integration*, mainly based on the contents of [37]. He also was invited speaker at the *Colloquium for Philippe Flajolet's 60th Birthday*, held at ENS in Paris, December 1-2, where he gave a talk entitled *Stochastic deformation of curves* [29].

Arnaud de La Fortelle participated to various panels and seminars. He served in IEEE ON-MOVE and WNEPC TPCs. He is member of the AHB30 committee within the TRB. He is member of the national geographic committee (Static and Dynamic Positioning). He is deputy member of the scientific and technical committee of the *pôles de compétitivité* MTA and Véhicules du futur. He is in charge of the JRU LaRA gathering Mines Paris and INRIA, with a third member, LIVIC, joining in 2008 and organized the scientific exchanges.

Jean-Marc Lasgouttes has been reviewer for the ANR program "Véhicules pour les transports terrestres", for applied mathematics journals (*Stochastic Processes and applications*, *European Journal of Operational Research*) and the IEEE ITSC'08 conference. He organizes the semi-regular seminar "Probabilité, Optimisation, Contrôle", which takes place in Rocquencourt, in collaboration with the Max-Plus project-team.

Fawzi Nashashibi is a scientific advisor at the Ecole Nationale d'Ingénieurs de Brest (ENIB). He is a peer reviewer for many national and international journals and conferences. This year, he is member of the Program Committee of the ICRA'09 international conference on advanced robotics. He is also an expert-reviewer in the domains of "intelligent transportation systems" and "virtual and mixed reality" for the french ANR and

PREDIT institutions in charge of selecting and financing french competitive projects. He is member of the FUDOLO Group steering the research activities in the field of vehicle real-time 3D localization on roads.

8.3. Teaching

Guy Fayolle has been a member of the committee of the French competitive examination *agrégation* of mathematics for 8 years until end of 2007, where during the last 4 years he was also in charge of the option Probability and Statistics. He stopped his service beginning of 2008, only participating to miscellaneous coordination meetings.

Jean-Marc Lasgouttes gave a semester course in data analysis at the “Magistère de Finance” of University Paris 1.

Fawzi Nashashibi is in charge of the “Vision” course and C++ programming at École des Mines de Paris (2nd year - MAREVA option); he gives lectures in 3-D graphics in the “Virtual reality and 3-D modelling” specialized course in the same establishment. He also gives two semesters courses on advanced programing at University of Saint-Denis (Paris 8).

8.4. Invitations

Guy Fayolle received invitations from the universities of Moscow, Newcastle and Cambridge; he was also asked to present some recent works at the seminars of ENS Ulm and IHP.

8.5. Miscellaneous

Guy Fayolle serves as elected member of the Scientific Board of INRIA

9. Bibliography

Major publications by the team in recent years

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