INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Imara

Informatique, Mathématiques et Automatique pour la Route Automatisée

Paris - Rocquencourt

Theme : Robotics

Activity Report

2009

Table of contents

1. Team

Research Scientist

Michel Parent [Team Leader]
Arnaud de La Fortelle [ENSMP, Vice Team Leader]
Philippe Deschamp [CR]
André Ducrot [DR]
Thierry Ernst
Guy Fayolle [DR emeritus, HdR]
Jean-Marc Lasgouttes [CR]
Fawzi Nashashibi [ENSMP, HdR]

Faculty Member

Gwenaëlle Toulminet [on leave from INSA-Rouen until September]

External Collaborator

Cyril Furtlehner [CR TAO (INRIA Saclay)]

Technical Staff

Armand Yvet [AI]
Samer Ammoun
Ines Ben Jemaa [since October]
Laurent Bouraoui [until March]
Clement Boussard
François Charlot
Alejandro Chinea Manrique De Lara [until March]
JinHyeock Choi [On leave from SAMSUNG–Korea until February]
Olivier Garcia [until February]
Carlos Holguin
Paulo Lopes Resende
Tony Noel
Jianping Xie [since May]
Hongliang Zhang

PhD Student

Yann Dumortier [until May]
Hao Li
Jennie Lioris
Mohamed Marouf
Victorin Martin [since December]
Luis Alfredo Martinez-Gomez
Olivier Mehani
Manabu Tsukada

Post-Doctoral Fellow

Yacine Khaled
Maxim Samsonov [since October]

Administrative Assistant

Chantal Chazelas [SAR]

Other

Diogo De Souza Dutra
Oumar Baba Diakhate [Master 2 internship from April to September]
Jong-Hyouk Lee
Satoru Noguchi

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 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...

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

Participants: Fawzi Nashashibi, Yann Dumortier, André Ducrot, Gwenaëlle Toulminet, Olivier Garcia, Laurent Bouraoui, Paulo Lopes Resende.

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: Yann Dumortier, Laurent Bouraoui, André Ducrot, Fawzi Nashashibi, Gwenaëlle 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

Participants: Fawzi Nashashibi, Laurent Bouraoui, Paulo Lopes 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 architecture 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)

Participants: Oumar Baba Diakhate, Guy Fayolle, Cyril Furtlehner, Jean-Marc Lasgouttes, Jennie Lioris, Victorin Martin.

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, JinHyeock Choi, Manabu Tsukada, Olivier Mehani, Jong-Hyouk Lee, Satoru Noguchi, Ines Ben Jemaa, Hongliang Zhang.

As witnessed by standardization activities, conferences, research work and ITS projects around the world, Internet-based communications in vehicular networks is now under the spotlight. Most of the research and development work in this area is only considering the Internet for multimedia communications or together with the use of 3G cellular links for Internet-based communications. Few teams are investigating the use of the TCP/IP suite of protocols and their extensions for real vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) 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, in a combined architecture allowing both V2V and V2I.

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 involvement in standardization bodies (ISO, IETF and ETSI).

Longer term activities 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.

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

3.6.1. Combination of MANET and NEMO

Mobile Adhoc Network (MANET) - or more precisely VANET (Vehicular Adhoc Network) in our specific case - routing protocols 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 (known as MANEMO) brings a number of technical and scientific issues in terms of addressing requirements (infrastructure-less vs infrastructure-based), 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. This includes GeoNetworking where a certain information, particularly safety information, is delivered to all or a set of vehicles located in a specific geographic area with minimum network overhead and minimum latency. GeoNetworking is the favored approach in 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 vehicles and services on offer.

3.6.4. Quality of Service (QoS)

The use of heterogeneous wireless technologies for vehicular networks incur varying delivering 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 intruder to corrupt the system which could cause accidents and traffic 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

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

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

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, Paulo Lopes Resende.

For an autonomous navigation system to be efficient, it is necessary to have three 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 respect 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 platooning and perform an intelligent monitoring of the crossroads such that no accidents could occur 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, Paulo Lopes 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 maneuver 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 propose an approach based on the “belief propagation” algorithm (BP), as a surrogate to an exact Markov Random Field (MRF) modelling [12]. A prior information composed of correlations among a large set of N variables, is encoded into a graphical model; this encoding is optimized with respect to an approximate decoding procedure (BP), which is used to infer hidden variables from an observed subset. We focus on the situation where the underlying data have many different statistical components, representing a variety of independent patterns. Considering a single parameter family of models we show how BP may be used to encode and decode efficiently such information, without solving the NP hard inverse problem yielding the optimal MRF. Contrary to usual practice, we work in the non-convex Bethe free energy minimization framework, and manage to associate a belief propagation fixed point to each component of the underlying probabilistic mixture. The mean field limit is considered and yields an exact connection with the Hopfield model at finite temperature and steady state, when the number of mixture components is proportional to the number of variables.

In addition, we provide an enhanced learning procedure, based on a straightforward multi-parameter extension of the model in conjunction with an effective continuous optimization procedure. This is performed using the stochastic search heuristic CMAES and yields a significant improvement with respect to the single parameter basic model (joint work with Anne Auger, project-team TAO).

5.2.2. Effect of normalization in Belief propagation algorithm

Participants: Oumar Baba Diakhate, 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. This year the focus has been set on extensions to the classical BP algorithm.

5.2.3. Belief propagation and Bethe approximation for traffic prediction

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

This work [64] 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 framework of the ANR project TRAVESTI (see 6.15), and of the upcoming FUI Pumas.

5.2.4. Multi-speed exclusion processes

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes.

We have considered in [24] 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. Traffic light prediction

Participants: Samer Ammoun, Jean-Marc Lasgouttes, Diogo De Souza Dutra.

As part of the Intersafe-2 project (see 6.11), we are working on an algorithm for automatic prediction of the next switching time for traffic light signals on intersections. The actual traffic light controller is considered as a black box, and the algorithm is to be embedded into the traffic light hardware, which implies important restrictions in terms of speed and memory. The method we devised consists in an interpretation of traffic light state in terms of phases and programs, on which a Markov-chain-based model is built. This model automatically recognizes the parts of the behaviour which is deterministic and builds prediction tables for the rest.

5.2.6. Markov growing trees

Participants: Guy Fayolle, Arnaud de La Fortelle.

We analyze the height process of so-called *Markov growing trees*. New edges appear according to a Poisson process of parameter λ and leaves can be deleted at a rate μ. The basic model was introduced in [63]. In the pure birth case (i.e. $\lambda = 0$, the distribution function of the height of the tree at time t does satisfy an interesting recursive nonlinear functional equation, which is studied mainly from an analytic point of view. The results obtained so far let appear interesting scalings, which apparently also hold for more general operators, leading thus to a kind of *invariance principle*. The next step will be to construct stationary laws from the transient process of interest.

5.2.7. Dynamical windings of random walks and exclusion models

Participant: Guy Fayolle.

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 [62]. 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.

5.2.8. 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 5.2.7.

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 [61], 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 [50], 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.

5.2.9. 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 [10], 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 central 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.

5.2.10. *Evaluation of collective taxi systems by event-driven simulation*

Participants: Jennie Lioris, Arnaud de La Fortelle.

We completed a made-to-measure simulation tool to study and evaluate the performance of a “collective taxis” transportation mode covering an entire urban area. In addition, we proceeded with the development and implementation of a technique to treat and analyse the results provided by the simulator.

Typically, we can employ statistics to provide quantitative answers qualifying the system performance and its reliability according to various models and decisional policies. We also started to study the decentralised approach, where clients appear randomly on the network, wishing to leave as soon as possible with no advanced reservations.

After initiating a great number of simulations on multiple fictitious inputs and various strategies, by analysing and comparing the corresponding results, we were then able to propose a methodology to perform the optimal management of each agent in the respective operating mode. Once that technique is obtained, a real application of the problem can be studied and analysed by following the concepts of the proposed methodology.

5.3. Communications with vehicles

5.3.1. *Vehicular Communication Architectures Design*

Participant: Thierry Ernst.

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. A performance evaluation of IPv6-based communication systems must thus be conducted to study IP applicability for packet flows with strong QoS and security constraints. This year we have significantly pushed for integration of IPv6 features and we contributed to ITS communication architecture standards specification, particularly at ISO TC204 WG16 [53] and COMeSafety (European Specific Support Action project proposing a reference ITS communication architecture for European projects) [52]. This work is partly done in the framework of the CVIS European project which can be described as a proof of concept of ISO CALM. As such we evaluated the system. in [23].

5.3.2. *Cross-Layer Architectures in Mobile Environment*

Participants: Olivier Mehani, Thierry Ernst.

Communication systems for mobile devices have reused a lot of the concepts and infrastructures which were developed for “legacy” wired network. Though functional, this approach is far from optimal and there is a need for network systems able to cope with, or even leverage, the inherent mobility of their hosts. Numerous designs of the network stack of protocols, sharing more information than what the OSI model suggested, have been proposed. These approaches are usually referred as *cross-layer design*. Early 2009 work have been focusing on the development of such a system, allowing to adapt a transport protocol to temporary disruptions due to mobility [34]. The limited applicability of cross-layer designs and their possibly degrading impact on the performance of the rest of the system however makes them hard to implement in complete systems. Additionally, network information needed for proper adaptation may not be available at a single node, as mobile devices could be parts of a mobile network (NEMO, *e.g.* in a vehicle) and not necessarily direct witnesses of network access changes. This calls for a distributed architecture akin to a cognitive network to better share information and foster better adaptation to the current conditions. An initial proposal of such an architecture was presented in [35]. Future work covers both areas of decentralized context information exchange within the NEMO and that of local decision based on this information. This work is related to the design of cross-layer architectures for vehicular networks at the standardization level (ISO CALM and ETSI TC ITS).

5.3.3. Geographic routing and addressing

Participants: Thierry Ernst, Yacine Khaled, JinHyeock Choi, Ines Ben Jemaa, Manabu Tsukada, Jong-Hyouk Lee, Satoru Noguchi, Hongliang Zhang.

This topic has been launched in October 2007 and is driving an important part of IMARA's resources given our commitments in the GeoNet project. The purpose is to study the combination of IPv6 and geographic-based routing into a performant communication architecture for vehicular networks. Since packets are delivered to multiple nodes, we are relying on multicast addressing and routing at the IP layer. However, IP multicast currently lacks the ability to route packets according to geographic information. We have therefore proposed several approaches to encode geographic information into IP multicast and we published [29], [28] on this topic. In addition to this, we are analyzing the feasibility and the performance of IP multicast when deployed in vehicular networks. The study of the deployment of IP multicast in VANETs is reported in [57].

5.3.4. Security and Location Privacy in vehicular networks

Participants: Jong-Hyouk Lee, Thierry Ernst, Olivier Mehani.

In the context of the GeoNet project, we developed a mechanism (Mobile Network Prefix Provisioning, MNPP in short) to advertise the IP address space of a vehicle to adjacent vehicles. This allows establishing a direct communication path between the vehicles. MNPP has been documented as an IETF Internet Draft [55]. However, exposing the address space of the vehicle over the air causes a number of security threats and location privacy issues that we are studying in the context of the MoboSeND project. We are thus developing a security mechanism to perform the advertisement of the address space in a safe way, with the constraint of infrastructure-less networks were nearby nodes don't know each other at first. We also conducted other work also focused on security and trust establishment for routing protocols within a vehicular ad-hoc network [22].

5.3.5. Combination of NEMO and MANET

Participants: Manabu Tsukada, Yacine Khaled, Thierry Ernst.

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:

- 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.

These topics are currently studied as part of a doctoral thesis which started in September 2007. We developed a tool to evaluate the performance [17], [41]. Our current results have been published in a number of papers: [13], [28]. Our IETF standardization activities [56], [51] are also related to this topic.

5.3.6. A messaging system for Peer-to-Peer applications in vehicle communication systems

Participants: Satoru Noguchi, Thierry Ernst.

In this research work we study (1) Cross-layered P2P messaging system for applications (2) IPv6 Service discovery; Harmonization between IPv6 (with mobility extensions) and applications. The objective is firstly to provide a common messaging mechanism for all applications in order to avoid an overlap of multiple messaging mechanisms in the application layer and second Regarding (2): It also provide service discovery mechanism for not only application layer services but also for network layer services. Currently we are collecting application requirements. This study is performed under the umbrella of the CVIS and Geonet workshops and as such we are studying now how to integrate our work into CVIS (CALM) stack.

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. 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 [53], ETSI TC ITS, COMeSafety [52]).

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

6.3. 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.

6.4. 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.

6.5. 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.

6.6. 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.

6.7. 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.

6.8. 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.

6.9. GeoNet

The GeoNet project has been set up in order to combine IPv6 and geographic addressing and routing. This combination is needed in order to guarantee interoperability between ITS communication architectures and Internet-based communications. It is used to deliver safety messages between cars but also between cars and the roadside infrastructure within a designated destination area and over multiple hops. The objective of the project is to specify the architecture where geographic routing is combined together with IPv6 features (NEMO, etc.). The project has so far produced an architecture, a reference specification of a geographic addressing and routing protocol with support for IPv6. This is currently under implementation.

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

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

6.10. 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).

6.11. 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.

6.12. CATS

Contractor: EU // Project duration: 4 years (2009-2013) // R&D grant: euros 400 000.

6.13. 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.

6.14. PICAV

Contractor: EU // Project duration: 4 years (2009-2013) // R&D grant: euros 500 000.

6.15. Travesti

This project addresses the problem of modelling large scale complex systems to provide predictions of their macroscopic behaviour. For application purpose, we focus here on the particular problem of the real-time prediction of traffic conditions on a road network.

Car traffic is a typical complex system which exhibits emerging phenomena such as jam formation and long distance interactions throughout a network. In particular we focus on the analysis of the traffic patterns delivered by the METROPOLIS traffic simulation software, in order to set up a prediction method based on a statistical physics modelling and message-passing algorithms.

Contractor: ANR // Project duration: 3 years (2009-2011) // R&D grant: euros 96 000.

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 [59], [58], [66] and drafts [51], [67], [65], [60].

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” [53].

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 [52].

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 CAOR at 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, provided reviews for various journal and conference papers. He is involved in several european and national projects related to IPv6 (CVIS, 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. 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) and NICTA in Australia.

Guy Fayolle is scientific advisor at the Robotics laboratory of Mines ParisTech. 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*. Guy Fayolle has been invited speaker at the conference *5e Rencontre de Statistiques*

Mathématiques, Bosantouval (33470 France), 3-5 june 2009. His talk *Scalings an hydrodynamic limits for multi-type exclusion processes via functional integration* could not be presented for medical reasons.

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 applied mathematics journals *QUESTA* and *European Journal of Operational Research*. 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.

The 25th “International Symposium on Computer and Information Sciences” (ISCIS 2010) will be held in London at the Royal Society, on September 22-24, 2010 and is organised by Imperial College, UK. Guy Fayolle is programme committee member.

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

[1] G. FAYOLLE, A. DE LA FORTELLE. *Large Deviation Principle for Markov Chains in Discrete Time*, in "Problems of Information Transmission", vol. 38, n^o 4, 2002.

[2] G. FAYOLLE, R. IASNOGORODSKI. *Two Coupled Processors: The Reduction to a Riemann-Hilbert Problem*, in "Z. Wahrscheinichkeitstheorie verw. Gebiete", vol. 47, 1979, p. 325-351.

[3] G. FAYOLLE, R. IASNOGORODSKI, V. A. MALYSHEV. *Random walks in the Quarter Plane*, Applications of Mathematics, n^o 40, Springer-Verlag, 1999.

[4] G. FAYOLLE, J.-M. LASGOUTTES. *Partage de bande passante dans un réseau : approches probabilistes*, n^o 4202, INRIA, 2001, http://hal.inria.fr/inria-00072420, 70 pages, Technical report.

[5] G. FAYOLLE, J.-M. LASGOUTTES. *Asymptotics and Scalings for Large Product-Form Networks via the Central Limit Theorem*, in "Markov Processes and Related Fields", vol. 2, n^o 2, 1996.

[6] G. FAYOLLE, V. A. MALYSHEV, M. V. MENSHIKOV. *Topics in the constructive theory of countable Markov chains*, Cambridge University Press, 1995.

[7] M. KAIS, N. HAFEZ, M. PARENT. *An Intelligent Vehicle Architecture for Automated Transportation in Cities*, in "Proceedings of European Control Conference (ECC'01), Porto", September 2001.

[8] A. DE LA FORTELLE. *Contribution à la théorie des grandes déviations et applications*, École nationale des ponts et chaussées, novembre 2000, Ph. D. Thesis.

Year Publications

Articles in International Peer-Reviewed Journal

[9] S. AMMOUN, F. NASHASHIBI. *Design and efficiency measurement of cooperative driver assistance system based on wireless communication devices*, in "Transportation Research Part C: Emerging Technologies", 2010, to appear.

[10] B. BERCU, P. CÉNAC, G. FAYOLLE. *On the Almost Sure Central Limit Theorem for Vector Martingales: Convergence of Moments and Statistical Applications*, in "J. Appl. Prob", 2009, p. 151–169.

[11] G. CHALLITA, S. MOUSSET, F. NASHASHIBI, A. BENSHRAIR. *Cooperative Method using GPS and Vision Systems to improve communicant vehicle positioning*, in "The Annals of Dunarea de Jos of Galati, Fascicle III: Electrotechnics, Electronic, Automatic Control, Informatics", vol. 32, n^o 1, 2009.

[12] C. FURTLEHNER, J.-M. LASGOUTTES, A. AUGER. *Learning Multiple Belief Propagation Fixed Points for Real Time Inference*, in "Physica A: Statistical Mechanics and its Applications", vol. 389, n^o 1, 2010, p. 149-163.

[13] Y. KHALED, M. TSUKADA, J. SANTA, J. CHOI, T. ERNST. *A usage oriented analysis of vehicular networks: from technologies to applications*, in "Journal of Communications", vol. 4, n^o 5, 2009, http://www.academypublisher.com/ojs/index.php/jcm/article/view/0405357368.

[14] J. NARANJO, L. BOURAOUI, R. GARCIA, M. PARENT, M. SOTELO. *Interoperable Control Architecture for Cybercars and Dual-Mode Cars*, in "Intelligent Transportation Systems, IEEE Transactions on", vol. 10, n^o 1, March 2009, p. 146-154, http://dx.doi.org/10.1109/TITS.2008.2011716.

[15] F. NASHASHIBI. *Vehicle tracking using a generic multi-sensor fusion approach*, in "International Journal on Vehicle Information and Communication Systems", vol. 2, n^o 1/2, 2009, p. 99-121.

[16] P. PAPADIMITRATOS, A. DE LA FORTELLE, K. EVENSSEN, R. BRIGNOLO, S. COSENZA. *Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation*, in "Communications Magazine, IEEE", vol. 47, n^o 11, November 2009, p. 84-95, http://dx.doi.org/10.1109/MCOM.2009.5307471.

[17] J. SANTA, M. TSUKADA, T. ERNST, O. MEHANI, A. F. GOMEZ-SKARMETA. *Assessment of VANET multi-hop routing over an experimental platform*, in "Int. J. Internet Protocol Technology", vol. 4, n^o 3, 2009, p. 158-172.

International Peer-Reviewed Conference/Proceedings

[18] S. AMMOUN, F. NASHASHIBI. *Real Time Trajectory Prediction for Collision Risk Estimation Between Vehicles*, in "Proceedings of the IEEE International Conference on Intelligent Computer Communication and Processing", August 2009.

[19] G. CHALLITA, S. MOUSSET, F. NASHASHIBI, A. BENSHRAIR. *Accurate Localisation of Communicant Vehicles equipped with GPS and Vision systems*, in "Fifth International Conference on Autonomic and Autonomous Systems (ICAS'09)", 2009, p. 195-199.

[20] G. CHALLITA, S. MOUSSET, F. NASHASHIBI, A. BENSHRAIR. *An application of V2V communications : Cooperation of vehicles for a better car tracking using GPS and Vision systems*, in "First IEEE Vehicular Networking Conference 2009 (IEEE VNC 2009)", 2009.

[21] G. CHALLITA, S. MOUSSET, F. NASHASHIBI, A. BENSHRAIR. *Particle Filters for Accurate Localization of Communicant Vehicles using GPS and Vision Systems*, in "7th ACS/IEEE International Conference on Computer Systems and Applications (AICCSA'09)", 2009, p. 238-242.

[22] T. CHEN, O. MEHANI, R. BORELI. *Trusted Routing for VANET*, in "ITST 2009, 9th International Conference on Intelligent Transport Systems Telecommunications, Piscataway, NJ, USA", M. BERBINEAU, M. ITAMI, G. WEN (editors), IEEE, October 2009, p. 647–652, http://www.nicta.com.au/research/research_publications/show?id=2152, Mines ParisTech affiliation only AU .

[23] T. ERNST, V. NEBEHAJ, R. SØRÅSEN. *CVIS: CALM Proof of Concept Preliminary Results*, in "9th International Conference on Intelligent Transport System Telecommunicaitons (ITST)", October 2009.

[24] C. FURTLEHNER, J.-M. LASGOUTTES. *A queueing theory approach for a multi-speed exclusion process.*, in "Traffic and Granular Flow '07", C. APPERT-ROLLAND (editor), Springer, 2009, p. 129-138, http://hal.archives-ouvertes.fr/hal-00175628/en/.

[25] G. GÂTÉ, A. BREHERET, F. NASHASHIBI. *Centralized fusion based algorithm for fast people detection in dense environment*, in "Proceedings of the IEEE International Conference on Robotics and Automation", 2009.

[26] G. GÂTÉ, F. NASHASHIBI. *An approach for robust mapping, detection, tracking and classification in dynamic environments*, in "Proceedings of the 2009 IEEE International Conference on Advanced Robotics", 2009.

[27] G. GÂTÉ, F. NASHASHIBI. *Fast algorithm for pedestrian and group of pedestrians detection using a laser scanner*, in "Proceedings of the 2009 IEEE Intelligent Vehicles Symposium", 2009.

[28] Y. KHALED, I. BEN JEMAA, M. TSUKADA, T. ERNST. *Application of IPv6 multicast to VANET*, in "9th International Conference on Intelligent Transport System Telecommunicaitons (ITST)", October 2009.

[29] Y. KHALED, M. TSUKADA, T. ERNST. *Geographical information extension for IPv6: application to VANET*, in "9th International Conference on Intelligent Transport System Telecommunicaitons (ITST)", October 2009.

[30] Y. KHALED, M. TSUKADA, J. SANTA, T. ERNST. *On the design of efficient Vehicular Applications*, in "IEEE Vehicular Technology Conference, Barcelona Espagne", 2009, http://hal.inria.fr/inria-00355878/en/.

[31] Y. KHALED, M. TSUKADA, J. SANTA, T. ERNST. *On the Design of Efficient Vehicular Applications*, in "Proc. IEEE 69th Vehicular Technology Conference VTC Spring 2009", April 26–29, 2009, p. 1–5, http://dx.doi.org/10.1109/VETECS.2009.5073727.

[32] E. LIORIS, G. COHEN, A. DE LA FORTELLE. *Simulation and Evaluation of Collective Taxi Systems*, in "Congrès International ATEC-ITS, Versailles, France", 4–5 février 2009.

[33] J. MARZAT, Y. DUMORTIER, A. DUCROT. *Real-time Dense and Accurate Parallel Optical Flow using CUDA*, in "International Workshop on Computer Vision and Its Application to Image Media Processing", 2009, http://hal.inria.fr/inria-00346710/.

[34] O. MEHANI, R. BORELI, T. ERNST. *Analysis of TFRC in Disconnected Scenarios and Performance Improvements with Freeze-DCCP*, in "MobiArch 2009, 4th ACM International Workshop on Mobility in the Evolving Internet Architecture, New York, NY, USA", J. OTT, K. TAN (editors), ACM, June 2009, http://www.nicta.com.au/research/research_publications/show?id=1405 AU .

[35] O. MEHANI, R. BORELI, T. ERNST. *Context-Adaptive Vehicular Network Optimization*, in "ITST 2009, 9th International Conference on Intelligent Transport Systems Telecommunications, Piscataway, NJ, USA", M. BERBINEAU, M. ITAMI, G. WEN (editors), IEEE, October 2009, p. 186–191, http://hal.inria.fr/inria-00426451/AU.

[36] O. MEHANI, R. BORELI, T. ERNST. *Context-Adaptive Vehicular Network Optimization*, in "ITST 2009, 9th International Conference on Intelligent Transport Systems Telecommunications, Lille France", M. BERBINEAU, M. ITAMI, G. WEN (editors), 10 2009, p. 186-191, http://hal.inria.fr/inria-00426451/en/.

[37] M. PARENT. *Automated Vehicles: the Future is Now*, in "14th IEEE Emerging Technologies and Factory Automation Conference", October 2009.

[38] M. PARENT. *Cooperative Automated Vehicles*, in "12th IFAC Symposium on Transp. Systems", August 2009.

[39] M. PARENT. *Optimisation des Transports Urbains: une Approche Hiérarchisée*, in "LT'2009 Séminaire International Logistique et Transports, Sousse, Tunisie", March 2009.

[40] T. RIDENE, F. NASHASHIBI. *Localisation précise d'un système de cartographie mobile pour la numérisation 3D d'environnement urbain*, in "Congrès ATEC-ITS France", 2009.

[41] J. SANTA, M. TSUKADA, T. ERNST, A. F. GOMEZ-SKARMETA. *Experimental analysis of multi-hop routing in vehicular ad-hoc networks*, in "Proc. 5th International Conference on Testbeds and Research Infrastructures for the Development of Networks. Communities and Workshops TridentCom 2009", April 6–8, 2009, p. 1–8, http://dx.doi.org/10.1109/TRIDENTCOM.2009.4976248.

[42] R. DE CHARETTE, F. NASHASHIBI. *Real Time Visual Traffic Lights Recognition Based on Spot Light Detection and Adaptive Traffic Lights Templates*, in "Proceedings of the 2009 IEEE Intelligent Vehicles Symposium", 2009.

[43] R. DE CHARETTE, F. NASHASHIBI. *Real time visual traffic lights recognition based on spot light detection and dynamic traffic lights templates*, in "Proceedings of the 16th World Congress and Exhibition on Intelligent Transport Systems and Services", 2009.

[44] R. DE CHARETTE, F. NASHASHIBI. *Real Time Visual Traffic Lights Recognition with Image Processing*, in "Proceedings of the 2009 IEEE International Conference on Advanced Robotics", 2009.

[45] R. DE CHARETTE, F. NASHASHIBI. *Traffic Light Recognition using Image Processing Compared to Learning Processes*, in "Proceedings of 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems", October 2009.

Workshops without Proceedings

[46] A. BARGETON, F. MOUTARDE, F. NASHASHIBI, B. BRADAI, L. CHANUSSOT. *Towards a reliable speed-limit assistant combining Traffic Sign Recognition with GPS information*, in "British Machine Vision Association (BMVA) technical meeting on “Vision for Automotive Applications”", 2009.

[47] C. BOUSSARD, B. D'ANDRÉA-NOVEL, N. HAUTIÈRE. *Estimation de la dynamique du véhicule pour une estimation embarquée de la distance de visibilité*, in "Journée Visibilité du GDR Robotique - GT2 véhicules Terrestres", 21 octobre 2009.

[48] C. FURTLEHNER, J.-M. LASGOUTTES, A. AUGER. *Inférence par propagation de croyance avec plusieurs points fixes et application à la prédiction de trafic routier*, in "Workshop on Statistical Physics And New Algorithms for Optimization and Inference", October 2009.

Scientific Books (or Scientific Book chapters)

[49] Y. KHALED, M. TSUKADA, J. SANTA, T. ERNST. *The Role of communication and network technologies in vehicular applications*, in "Advances in Vehicular Ad-Hoc Networks: Developments and Challenges", n^{o} 15, IGI Global (formerly Idea Group Inc.), 2010.

Research Reports

[50] G. FAYOLLE, C. FURTLEHNER. *Hydrodynamic Limit of Multi-type Exclusion Processes via Functional Integration*, INRIA, 2010, to appear, Technical report.

Patents and standards

[51] R. BALDESSARI, T. ERNST, A. FESTAG, M. LENARDI. *Automotive Industry Requirements for NEMO Route Optimization*, n^{o} Internet-Draft draft-ietf-mext-nemo-ro-automotive-req-02 (work in progress), IETF, January 2009.

[52] COMESAFETY. *European ITS Communication Architecture - Overall Framework - Proof of Concept Implementation*, n^o Version 2.6 (work in progress), COMeSafety Specific Support Action, October 2009.

[53] ISO. *Intelligent Transport Systems - Communications access for land mobiles (CALM) - IPv6 networking*, n^o ISO/DIS 21210, ISO Technical Committee 204 WG16, September 2009, Work in progress.

[54] C. LAURGEAU, A. DE LA FORTELLE, B. STEUX. *Système et procédé d'information sur le trafic dans un réseau routier*, n^o 0851809, 2009.

[55] J.-H. LEE, M. TSUKADA, T. ERNST. *Mobile Network Prefix Provisioning*, n^o Internet-Draft draft-jhlee-mext-mnpp-00.txt (work in progress), IETF, October 2009.

[56] R. WAKIKAWA, T. ERNST, K. NAGAMI, V. DEVARAPALLI. *Multiple Care-of Addresses Registration*, n^o Request For Comments (RFC) 5648, IETF, July 2009.

Other Publications

[57] I. BEN JEMAA. *IPv6 multicast application in vehicular communication*, Ecole Supérieure d'Ingénierie et de Technologie (ESPRIT), 2009, Masters thesis.

References in notes

[58] T. ERNST. *Network Mobility Support Goals and Requirements*, n^o 4886, IETF, July 2007, Request For Comments.

[59] T. ERNST, H.-Y. LACH. *Network Mobility Support Terminology*, n^o 4885, IETF, July 2007, Request For Comments.

[60] T. ERNST, N. MONTAVONT, R. WAKIKAWA, C. NG, K. KULADINITHI. *Scenarios for Using Multiple Interfaces and Global Addresses*, n^o draft-ietf-monami6-multihoming-motivation-scenario-03.txt, IETF, May 2008, Work in progress, Internet Draft.

[61] G. FAYOLLE, C. FURTLEHNER. *Stochastic Dynamics of Discrete Curves and Exclusion Processes. Part 1: Hydrodynamic limit of the ASEP System*, n^o 5793, INRIA, December 2005, http://hal.inria.fr/inria-00001131, Technical report.

[62] G. FAYOLLE, C. FURTLEHNER. *Stochastic Dynamics of Discrete Curves and Multi-Type Exclusion Processes*, in "Journal of Statistical Physics", vol. 127, n^o 5, June 2007, p. 1049-1094.

[63] G. FAYOLLE, M. KRIKUN, J.-M. LASGOUTTES. *Birth and Death Processes on Certain Random Trees: Classification and Stationary Laws*, in "Probability Theory and Related Fields", vol. 128, n^o 3, 2004, p. 386-418, http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s00440-003-0311-1, Digital Object Identifier: 10.1007/s00440-003-0311-1.

[64] C. FURTLEHNER, J.-M. LASGOUTTES, A. DE LA FORTELLE. *A Belief Propagation Approach to Traffic Prediction using Probe Vehicles*, in "Intelligent Transportation Systems Conference, ITSC'07", 2007, p. 1022-1027, http://hal.inria.fr/hal-00175627/.

[65] N. MONTAVONT, R. WAKIKAWA, T. ERNST, C. NG, K. KULADINITHI. *Analysis of Multihoming in Mobile IPv6*, n^{o} draft-ietf-monami6-mipv6-analysis-05.txt, IETF, May 2008, Work in progress, Internet Draft.

[66] C. NG, T. ERNST, E. PAIK, M. BAGNULO. *Analysis of Multihoming in Network Mobility Support*, n^{o} 4980, IETF, October 2007, Request For Comments.

[67] R. WAKIKAWA, T. ERNST, V. DEVARAPALLI, K. NAGAMI. *Multiple Care-of Addresses Registration*, n^{o} draft-ietf-monami6-multiplecoa-10, IETF, November 2008, Work in progress, Internet Draft.