IN PARTNERSHIP WITH:
**CNRS**

**Institut polytechnique de Grenoble**

**Université Joseph Fourier (Grenoble 1)**

# Activity Report 2011

# Project-Team NECS

## Networked Controlled Systems

IN COLLABORATION WITH: Grenoble Image Parole Signal Automatique (GIPSA)

RESEARCH CENTER
**Grenoble - Rhône-Alpes**

THEME
**Modeling, Optimization, and Control of Dynamic Systems**

# Table of contents

## Project-Team NECS

**Keywords:** Distributed Algorithms, Network Modeling, Network Control, Quality Of Service, Robust Control, Nonlinear Control

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# 2. Overall Objectives

## 2.1. Introduction

The NeCS project-team goal is to develop a new control framework for assessing problems raised by the consideration of new technological low-cost and wireless components, the increase of systems complexity, and the distributed and dynamic location of sensors (sensor networks) and actuators. In this framework, control design is performed under general resources constraints including communication, computation, and energy. In that, the team targets an innovative step forward in the feedback design for networked controlled distributed systems by the development of combined control, computing & communication co-design. The project-team is bi-located at INRIA (Montbonnot) and at the GIPSA-LAB (at the Grenoble campus).

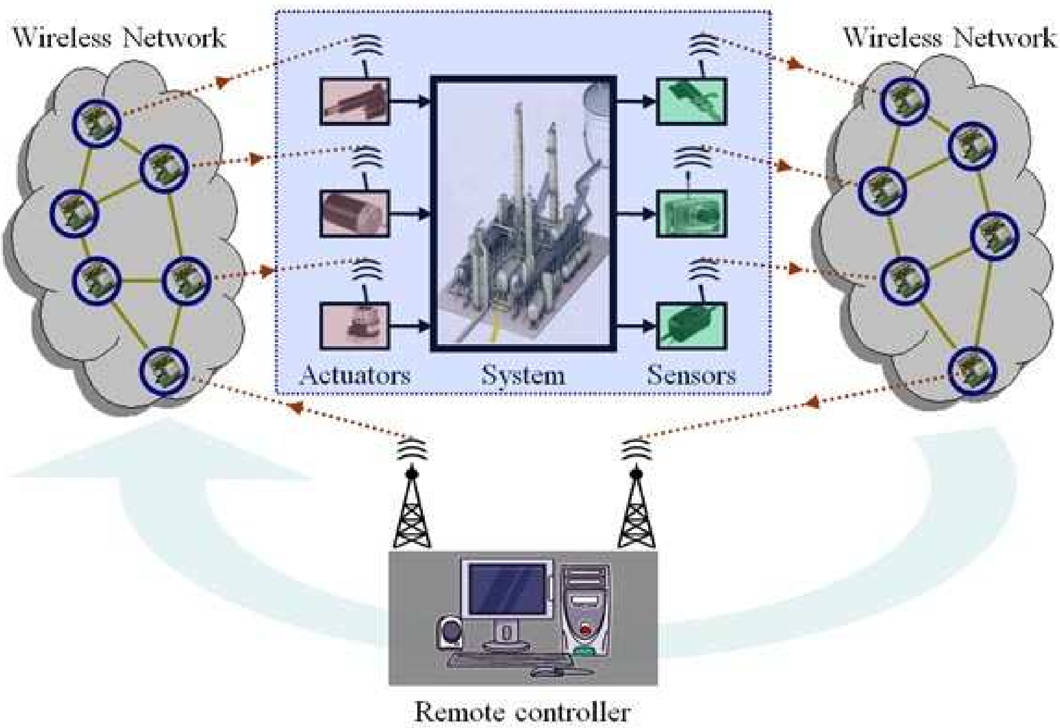


*Figure 1. Overview of NeCS systems.*

The field of Networked Controlled Systems (NCS) refers to feedback systems controlled *over* networks, as shown in Fig 1. Such systems present new control problems posed by the consideration of several factors, such as: new technological components (i.e., wireless sensors, RF communications, adhoc networks, etc.), increase of systems complexity (i.e., increase in the number and variety of components), the distributed location of sensors and actuators, and computational constraints imposed by their embedded nature (i.e., embedded systems and systems on-chip). In this class of systems, the way that the information is transferred and processed (information constraints), and the manner in which the computation/energy resources are used (resources management), have a substantial impact in the resulting stability and performance properties of the feedback controlled systems. Inversely, the already designed feedback system can be affected by the properties of the channel transmission (latency, fading, delay jitter, lost of data, etc.), and the way that the computational and energy resources are used.

## 2.2. Highlights

The most relevant events and activities for the NeCS team in 2011 are the following:

- The organization of the 3rd annual Consortium Meeting of the FeedNetBack European project, held at INRIA in Montbonnot, on October 11-12th 2011. A review meeting session and scientific presentations from peoples involved in the FeedNetBack project have been organized.
- The recruitment of a new researcher in the team: Hassen Fourati has joined the NECS team as an UJF Associate Professor (Maître de Conférences), since September 2011.
- During 2011, the NECS team published 28 communications in national and international conferences, 8 papers in international journals, 1 scientific book chapter, 11 research reports and 1 patent.

# 3. Scientific Foundations

## 3.1. Multi-disciplinary nature of the project

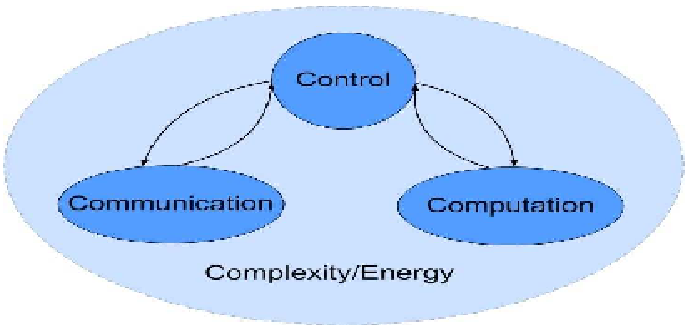


*Figure 2. Relation of the NCS area with the fields of: Control, Communication, Computation.*

The team's project is to investigate problems in the area of NCS with the originality of integrated aspects on computation, communication and control. The combination of these three disciplines requires the interplay of the multi-disciplinary fields of: communication, real-time computation, and systems theory (control). Figure 2, shows the natural interaction between disciplines that concern the NeCS project. The arrows describe the direction in which these areas interact, i.e.

$(a)$ *Control in Communication*

$(b)$ *Communication in Control*

$(c)$ *Computation in Control*

$(d)$ *Control in Computation*

Complexity and energy-management are additional features to be considered as well. Complexity here refers to the problems coming from: wireless networks with varying interconnection topologies, multi-agent systems coordination, scaling with respect to a growing number of sensors. Energy management concerns in particular the efficient handling of energy in wireless sensors, and means an efficient way to handle both information transmission and computation.

### 3.1.1. (a) Control in Communication

This topic is the study of how control-theoretic methods can be applied in order to solve some problems found in the communication field. Examples are: the Power control in cell telephones, and the optimal routing of messages in communication networks (Internet, sensor networks).

### 3.1.2. (b) Communication in Control

This area concerns problems where communication and information theory interact with systems theory (control). As an example of a classical paradigm we can mention the stabilization problem under channel (communication) constraints. A key result here [89] was to show that it was generically impossible to stabilize a linear system in any reasonable sense, if the feedback channel's Shannon classical capacity $C$ was smaller than the sum of the logarithms, base 2, of the unstable eigenvalues. In other words, in order to be able to cope with the stabilization problem under communication constraints, we need that

$$C > \sum_i \log_2 \lambda_i$$

where the $\lambda_i's$ are unstable eigenvalues of the open loop system. Intuitively, this means that the rate of information production (for discrete-time linear systems, the intrinsic rate bits/time equals $\sum_i \log_2 \lambda_i$) should be smaller than the rate of information that can be transmitted throughout the channel. In that way, a potentially growing signal can be cached out, if the information of the signal is sent via a channel with fast enough transmission rate. In relation to this, a problem of interest is the coding and control co-design. This issue is motivated by applications calling for data-compression algorithms aiming at reducing the amount of information that may be transmitted throughout the communication channel, and therefore allowing for a better resource allocation and/or for an improvement of the permissible closed loop system bandwidth (data-rate). Networked controlled systems also constitute a new class of control systems including specific problems concerned by delays. In NCS, the communication between two agents leads unavoidably to transmission delays. Also, transmission usually happens in discrete time, whereas most controlled processes evolve in continuous time. Moreover, communication can induce loss of information. Our objectives concern the stabilization of systems where the sensor, actuator and system are assumed to be remotely commissioned by a controller that interchanges measurements and control signals through a communication network. Additional dynamics are introduced due to time-varying communication delays, asynchronous samplings, packets losses or lack of synchronization. All those phenomena can be modelled as the introduction of time-delays in the closed loop system. Even if these time-delay approaches can be easily proposed, they require careful attention and more complex analysis. In general, the introduction of delays in a controlled loop leads to a reduction of the performance with respect to the delay-free situation and could even make the systems unstable. Our objective is to provide specific modelling of these phenomena and to develop dedicated tools and methodologies to cope with stability and stabilization of such systems.

### 3.1.3. (c) Computation in Control

This area concerns the problem of redesigning the control law such as to account for variations due to the resource allocation constraints. Computation tasks having different levels of priority may be handled by asynchronous time executions. Hence controllers need to be re-designed as to account for non-uniform sampling times resulting in this framework. Questions on how to redesign the control laws while preserving its stability properties are in order. This category of problems can arise in embedded systems with low computation capacity or low level resolution.

### 3.1.4. (d) Control in Computation

The use of control methods to solve or to optimize the use of computational resources is the key problem in this area. This problem is also known as a scheduling control. The resource allocations are decided by the controller that try to regulate the total computation load to a prefixed value [20]. Here, the system to be regulated is the process that generates and uses the resources, and not any physical system. Hence, internal states are computational tasks, the control signal is the resource allocation, and the output is the period allowed to each task.

### 3.1.5. (c + d) Integrated control/scheduling co-design

Control and Computation co-design describes the possibility to study the interaction or coupling between the flows $(c)$ and $(d)$. It is possible, as shown in Fig. 3, to re-frame both problems as a single one, or to interpret such an interconnection as the cascade connection between a computational system, and a physical system. In our framework the feedback scheduling is designed w.r.t. a QoC (Quality of Control) measure. The QoC criterion captures the control performance requirements, and the problem can be stated as QoC optimization under constraint of available computing resources. However, preliminary studies suggest that a direct synthesis of the scheduling regulator as an optimal control problem leads, when it is tractable, to a solution too costly to be implemented in real-time [68]. Practical solutions will be found in the currently available control theory and tools or in enhancements and adaptation of current control theory. We propose in Fig. 3 a hierarchical control structure: besides the usual process control loops we add an outer control loop which goal is to manage the execution of the real-time application through the control of the scheduling parameters of the inner loops. Together with the outer loop (working on a periodic sampled time scale) we also need a scheduling manager working on a discrete events time scale to process exception handling and admission control. The task periods directly affect the computing load, they have been chosen as actuators. They can be implemented through software variable clocks. As timing uncertainties cannot be avoided and are difficult to model or measure, we currently design robust control algorithms using the $H_\infty$ control theory, which have been successfully simulated and experimentally validated [87]. This methodology is supported by the software ORCCAD (see Section 5.1) where a run-time library for multi-rate multitasking has been developed and integrated. It will be further improved using a QoS-based management of the timing constraints to fully benefit from the intrinsic robustness of closed loop controllers w.r.t. timing uncertainties.

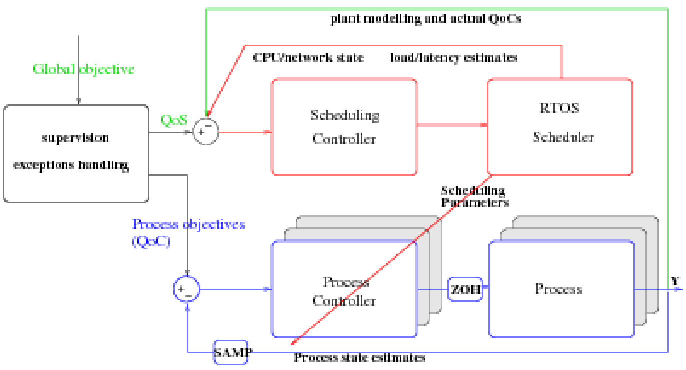


*Figure 3. Hierarchical control structure.*

## 3.2. Main Research Directions

The main objective of the project is to develop a unified control, communication, computing co-design methodology explicitly accounting for all the components involved in the system controlled over a network. This includes quantifier properties, scheduling parameters, encoder/decoder, alphabet length, bandwidth of the transmission media (wire or wireless), delays, resource allocation, jitter, etc. These components, including the control laws, should be designed so as to optimize performance/stability trade-offs resulting from the ceiling of the computing resources, the channel capacity limitations and the quality of the send/received information protocols. More informations about the main research directions of the team can be found in [1], [3],[2], [4] [5], [6], [7], [8], [9] and [10].

In short, the project is centered along the following 3 main axes:

1. **Control under Communications Constraints.** One well established topic along this axis concerns the coding and control co-design. That is, the design of new code alphabets simultaneously than the design of the control law. Or equivalently, the ability of designing codes containing information pertained to the system model and the control law. The objective being the improvements of the overall closed loop performances. Besides this matter, additional improvements pertain to the field of the information theory are also in order.
2. **Control under Computational resources constraints.** The main objective here is the design of control loops by explicitly accounting for the network and/or the computing resources. Dynamic allocation of such resources depends on the desired controlled systems specifications. Keys aspects to be considered are: the design of controllers with variable sampling time, the robustness with respect to time uncertainties such as the input/output latencies, the global control of resources and its impact over the performance and the robustness of the system to be controlled. We aim to provide an integrated control and scheduling co-design approach [1].
3. **Controlling Complexity.** Design and control of partially cooperative networked (possible also multi-agent) systems subject to communication and computational constraints. Here, a large number of entities (agents), having each its own goal share limited common resources. In this context, if there is no minimum coordination, dramatic consequences may follow, on the other hand, total coordination would be impossible because of the lack of exhaustive, reliable and synchronous information. Finally, a local network of strategies that are based on worst-case assumptions is clearly far from being realistic for a well designed system. The aim of this topic is to properly define key concepts and the relevant variables associated to the above problem (sub-system, partial objective, constraints on the exchanged data and computational resources, level of locally shared knowledge, key parameters for the central level, etc).

# 4. Application Domains

## 4.1. Application domains

Closing feedback loops around Wireless sensor networks offer new challenges and new opportunities for the area of control. Several new application areas can be enabled, or enhanced if systematic methods are developed for the design of NCS. Examples include:

- Intelligent buildings, where sensor information on $CO_2$ concentration, temperature, room occupancy, etc. can be used to control the heating, ventilation and air conditioning (HVAC) system under multi-objective considerations of comfort, air quality, and energy consumption.
- Intelligent transportation systems, where traffic flow or density can be measured using novel wireless technologies and used to determine control inputs such as on-ramp metering schemes and variable message signs.
- Disaster relief operations, where data collected by sensor networks can be used to guide the actions of rescue crews and operate automated rescue equipment.
- Surveillance using swarms of Uninhabited Aerial Vehicles (UAVs), where sensor information (from sensors on the ground and/or on-board the vehicles) can be used to guide the UAVs to accomplish their mission.
- Environmental monitoring and exploration using schools of Autonomous Underwater Vehicles (AUVs), where underwater sensors and communication are used to guide the AUVs.
- Infrastructure security and protection using smart camera networks, where the images collected are shared among the cameras and used to control the cameras themselves (pan-tilt-zoom) and ensure tracking of potential threat.

In particular, the team is already involved in the areas described in detail below.

### 4.1.1. Vehicular transportation systems

#### 4.1.1.1. Car industry

Car industry has been already identified as a potential homeland application for NCS [76], as the evolution of micro-electronics paved the way for introducing distributed control in vehicles. In addition, automotive control systems are becoming the more complex and iterative, as more on-board sensors and actuators are made available through technology innovations. The increasing number of subsystems, coupled with overwhelming information made available through on-board and off-board sensors and communication systems, rises new and interesting challenges to achieve optimal performance while maintaining the safety and the robustness of the total system. Causes of such an increase of complexity/difficulties are diverse: interaction between several control sub-systems (ABS, TCS, ESP, etc.), loose of synchrony between sub-systems, limitations in the computation capabilities of each dedicate processor, etc. The team had several past collaborations with the car industry (Renault since 1992, and Ford). In addition, an ANR project, named VOLHAND, has been started in collaboration with INRETS, JTEKT, Fondation Hopale, LAMIH, CHRU. It aims at developing a new generation of electrical power-assisted steering specifically designed for disabled and aged persons.

#### 4.1.1.2. Intelligent transportation systems

Throughout the world, roadways are notorious for their congestion, from dense urban network to large freeway systems. This situation tends to get worse over time due to the continuous increase of transportation demand whereas public investments are decreasing and space is lacking to build new infrastructures. The most obvious impact of traffic congestion for citizens is the increase of travel times and fuel consumption. Another critical effect is that infrastructures are not operated at their capacity during congestion, implying that fewer vehicles are served than the amount they were designed for. Using macroscopic fluid-like models, the NeCS team has initiated new researches to develop innovative traffic management policies able to improve the infrastructure operations. This activity is currently focused on automatic model calibration and traffic prediction, two important items to implement efficient Intelligent Transportation Systems (ITS) such as traffic responsive ramp metering and varying speed limit as well as producing relevant user information. The team is currently setting up a consortium with local authorities involved in traffic management to build to a demonstrator called GTL (Grenoble Traffic Lab). One target of this activity is to transfer part of the developed technology to a start-up named Karrus.

### 4.1.2. Underwater systems

Underwater systems, as presently used or intended by the offshore industry and marine research, are subject to severe technological constraints. In AUVs, the on-board power is limited and calls for both control and computing optimization. The links between the master and slave nodes use acoustic devices, which have a very low bandwidth and are subject to frequent transient loss, thus calling for sharing the decisional process among the nodes and for a robust implementation of the distributed control, taking into account the communication network features. These constraints together with the potential cost of failures make these systems good candidates for safe and flexible control, communication and computing co-design. The team already got a significant experience in this domain with a past collaboration with IFREMER and other EU projects. The projects CONNECT and FeedNetBack are dealing with this type of problems (see Sections 8.2 and 8.3).

### 4.1.3. Systems on chip

Achieving a good compromise between computing power and energy consumption is one of the challenge in embedded architecture of the future. This management is especially difficult for 45nm or 32nm known to be at the limit of the scalability. Automatic control loops have therefore to be designed in order to make the performance fit the requirement in order to minimize the energy loss in a context of highly unknown performance of the chip. The main objective is to control the computing power and the consumption using the voltage and frequency automatically according to the requirements of the OS. For this, appropriate sensors must be implemented on the chip and a high-performance repartition between hardware and software implementation must be made.

# 5. Software

## 5.1. ORCCAD

**Participants:** Daniel Simon [correspondant], Soraya Arias [SED], Roger Pissard-Gibollet [SED].

ORCCAD is a software environment that allows for the design and implementation of the continuous and discrete time components of complex control systems, e.g. robotics systems which provided it first ground [64]. It also allows the specification and validation of complex missions to be performed by the system. It is mainly intended for critical real-time applications, in which automatic control aspects (servo loops) have to interact narrowly with the handling of discrete events (exception handling, mode switching). ORCCAD offers a complete and coherent vertical solution, ranging from the high level specification to real-time code generation. The ORCCAD V3 software was designed with proprietary tools that moreover are now becoming obsolete. ORCCAD V4 is currently deeply re-engineered to be compliant with open-source and free software tools (Java/Eclipse). Current targets are Linux (Posix threads) and Xenomai, a real-time development framework cooperating with the Linux kernel (http://www.xenomai.org). ORCCAD is supported by the *Support Expérimentations & Développement (SED)* service of INRIA-Rhône-Alpes. ORCCAD is used by the experimental robotics platforms of INRIA-Rhône-Alpes and by the Safenecs ANR project in a real-time simulator of a X4 drone. New functionalities and updates are developed jointly by the *SED* service and researchers of the NECS and SARDES teams. Web page: http://orccad.gforge.inria.fr.

## 5.2. MASim

**Participants:** J. Dumon [contact person], P. Bellemain [GIPSA-Lab], S. Nicolas [PROLEXIA], N. Maciol [PROLEXIA], F. Martinez [ROBOSOFT], J. Caquas [ROBOSOFT].

MASIM is a tool that has been adapted from our former multiagent simulator MUSim (MUSim=MASim + ConnectSim + ConnectIHM). It integrates agent's models, communication media including their limitations, heterogeneous network, and all the variants of the multi-agent control strategies. Besides the models and simulation engine, the simulation can be replayed through a GUI, an interactive graphical interface which is used to visualise and interpret the state of the multi-agent control system and communication topology. The validation scenario is a real-size application enough complex to enforce the pertinence of our results. The simulator MASim is now being used as an open research tool for various applications in the field of multi-agents networked systems, particularly within the FeedNetBack project (see Fig. 4).

# 6. New Results

## 6.1. Communication and control co-design for networked systems

### *6.1.1. Energy-aware communication and control co-design in wireless networked control systems*

**Participants:** C. Canudas de Wit [Contact person], N. Cardoso de Castro, F. Garin.

This work is the topic of the PhD thesis of N. Cardoso de Castro. We have considered an event-based approach to energy-efficient management of the radio chip in the sensor node of a wireless networked control system [54], [66]. Indeed, as we had pointed out in the review paper [67], the radio is the main energy consumer, and intermittent data transmission allows one to reduce the use of the radio. While the existing literature in the control community on event-based control only addresses policies using two radio-modes (Transmitting/Sleep), our work follows some considerations on the radio-chip modes well-known in the communication networks literature, and introduces some intermediate radio-modes, which consume more energy than 'Sleep' but allow to reach the transmitting mode consuming less energy in the transition. We propose an event-based radio-mode switching policy, which allows to perform a trade-off between energy

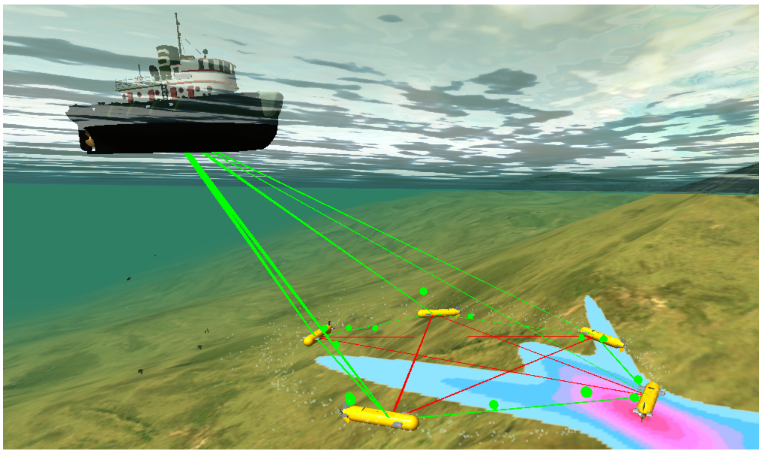

*Figure 4. A scenario's view obtained with* MASIM.

saving and performance of the control application. To this end, a switched model describes the system, taking into account control and communication. The optimal switching policy is computed using Dynamic Programming. This work is described in [66] and in a journal paper (in preparation). A further research direction is the exploration of receding-horizon techniques (Model Predictive Control), to solve a slightly modified formulation of the same problem. This research is in collaboration with Dr. Daniel Quevedo, senior lecturer at the University of Newcastle, Australia, in particular during a three-months visit of N. Cardoso de Castro at University of Newcastle.

### 6.1.2. Adaptive Delta Modulation in Networked Controlled Systems with bounded disturbances

**Participants:** C. Canudas de Wit [Contact person], F. Gomez-Estern [University of Sevilla], F. R. Rubio [University of Sevilla].

In the context of communication and control co-design for networked systems, this work investigates the closed-loop properties of the differential coding scheme known as Delta Modulation when used in feedback loops within the context of linear systems controlled through a communication network [19]. We propose a new adaptive scheme with variable quantization step, by defining an adaptation law exclusively in terms of information available at both the transmitter and receiver. With this approach, global asymptotic stability of the networked control system is achieved for a class of controllable (possibly unstable) linear plants. Moreover, thanks to the globally defined switching policy, this architecture enjoys a disturbance rejection property that allows the system to recover from any finite–time unbounded disturbance or communication loss.

### 6.1.3. Control, communication, computation (3C) co-design: Multi - level classification and formulation

**Participants:** C. Canudas de Wit [Contact person], A. Farhadi [University of Melbourne].

We introduce here an integration framework for Control/Communication/Computation (3C) co-design based on the motivating example of fleet control of Autonomous Underwater Vehicles (AUVs) [35], [75]. Specifically, we address the problem of almost sure stability of an unstable system with multiple observations over packet erasure channel, with emphasis on coding computational complexity. We look at the tradeoff between duty cycle for feedback channel use, coding computational complexity, and performance. We compare coding computational complexity and performance for two cases: a) No feedback channel at all, and b) Feedback channel all the time. It is shown that the strategy of using feedback channel results in a better performance.

## 6.2. Collaborative distributed consensus algorithms for control and estimation

### 6.2.1. Distributed Control

**Participants:** A. Seuret [Contact person], C. Canudas de Wit, L. Briñón Arranz, G. Rodrigues de Campos, K. H. Johansson [KTH].

The first contribution in this area deals with the source-seeking problem in which the task is to locate the source of some signal using a fleet of autonomous underwater vehicles. The objective is here to use the underwater vehicles equipped with appropriate sensors as a mobile sensors network. In [28] and [29], we present a method which allows estimating the gradient of the signal propagation using a distributed consensus filters [27]. To do so, we consider a group of vehicles uniformly distributed in a fixed circular formation. We then show that this distributed consensus algorithm converges to good approximation of the gradient of the signal propagation. The algorithm takes into account the communication constraints and depends on direct signal measurements. Our approach is based on the previous results in formation control to stabilize the fleet to elastic formations which can be time-varying [29] and in a collaborative source-seeking algorithm proposed earlier by members of the team. The results are supported through computer simulations.
The second contribution on collaborative control concerns the design and analysis of a distributed algorithm whose goal is symmetric robot deployment. This activity results from the collaboration between INRIA and KTH provided by the visit of G. Rodrigues de Campos (PhD student) at KTH during six month. The objective is here to propose a hierarchical control strategy composed of two stages. The first one corresponds to an algorithm for swarm dispersion and a second concerns the design of a additional algorithm which minimizes the inter-agent angles. In this context, the behavior of each vehicle depends only on the relative positions of agents it can sense. The article submitted to ICRA'12 [84], presents some simulation examples for different configuration support the derived theoretical results.

### 6.2.2. Distributed Estimation

- Collaborative protocols for estimation and control
  **Participants:** A. Kibangou [Contact person], A. L. F. Almeida [Universidade Federal do Ceara].

  In wireless communication systems, spatial diversity plays a key role in combating signal fading arising from multipath propagation. As long as the transmitter is equipped with multiple antennas, it is well known that spatial diversity can be exploited further at the transmitter by means of space-time coding [88]. In contrast to conventional (single-user) space-time coding/decoding, when dealing with cooperative wireless networks, spatial diversity must resort to distributed space-time coding/decoding, where a collection of distributed antennas belonging to multiple terminals work in a coordinated way to encode/decode the transmitted information [85].
  For this purpose, we have extended the Khatri-Rao Space time coding method proposed in [86] to cooperative networks (see Fig. 5). For cooperating nodes having a single antenna, these nodes constitute a virtual antenna array at both transmitting and receiving front-end. At each node, the received data can be viewed as slices of a third-order tensor. Therefore, retrieving the informative data is achieved by means of a CP tensor decomposition using an Alternating Least Squares (ALS) algorithm for example. When all the slices cannot be gathered at the same node, for storage resources limitations for example, a distributed ALS method can be used as in [77], which is an average consensus based method. In a consensus problem, a group of network nodes try to reach agreement on a given quantity of interest that depends on their local values [79]. Instead of using a standard consensus method where convergence is achieved asymptotically, we have proposed a finite time average consensus approach that relies on the knowledge of the graph topology. The proposed algorithm and its performance evaluation by means of simulations are described in [37].
- Kalman filtering based distributed fault detection and isolation
  **Participants:** A. Kibangou [Contact person], F. Garin, S. Hachour, A. Esna Ashari.

  This year, we have started a research activity related to distributed fault detection and isolation. Our first work has been the master thesis of S. Hachour on the monitoring of a solar farm.

Indeed, stimulated by increasing energy demand and ecological concerns, clean energy production with renewable resources is a key research topic that presents a largely unexplored potential of development.
For this purpose, solar farms constitute power plants of the future. In such systems, electricity is produced thanks to the combined action of a large number of interconnected modules (solar panels). Each module individually produces energy, but only their interconnection allows reaching the global task of a relevant energy production. Due to the interconnection topology, a local fault on a given module can induce damageable effects on the whole network. In order to detect and localize a fault, a sensor network can be deployed over the farm. Thanks to the recent advances in wireless communications, the sensors can be equipped with wireless devices, creating a network of communicating sensors. A classical way to exploit such a network would be to create a hierarchical (tree-like) structure which conveys all measurements to a centralized computer which would analyze all data. However, a failure in a communication link or in the centralized computer would result in breakdown of the whole fault detection system, which is an unacceptable risk in an application domain of strategic importance such as a power plant. Therefore we have proposed a decentralized approach that relies on local data aggregation using the computing and communicating resources of the sensor nodes. As a consequence, nodes cooperation produces a global decision, available at each point of the network, and computable even in the case where a few sensors or links are unavailable.
The monitoring procedure is achieved in a distributed way using a Kalman filtering approach. Now, by considering the sensor network as the system of interest, we try to derive distributed estimation methods that are robust to malicious entities and monitoring methods to detect anomalies in the system due to these malicious entities or malfunctioning of the network. These issues are addressed by A. Esna Ashari during his post-doctoral stay in our team.

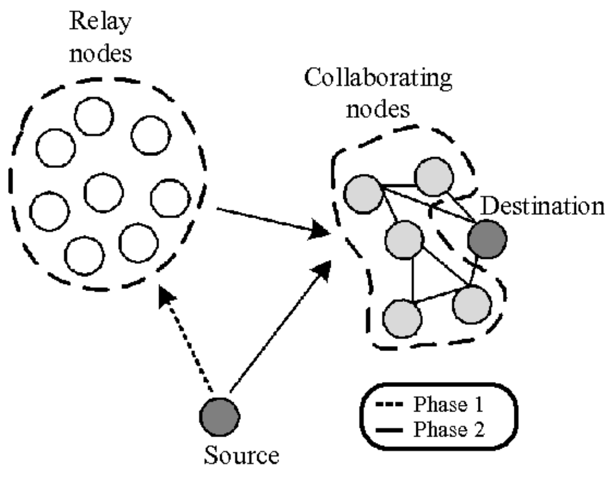


*Figure 5. Cooperative communication system.*

### *6.2.3. Distributed Consensus*

- Finite-time distributed average consensus on sensor networks
  **Participant:** A. Kibangou [Contact person].

  Nowadays, several distributed estimation algorithms are based on the average consensus concept. Average consensus can be reached using a linear iterations scheme where each node repeatedly

updates its value as a weighted linear combination of its own value and those of its neighbors. The main benefit of using a linear iterations scheme is that, at each time-step, each node only has to transmit a single value to each of its neighbors. Based on such a scheme, several algorithms have been proposed in the literature. However, in the majority of the proposed algorithms the weights are chosen so that all the nodes asymptotically converge to the same value. Sometimes, consensus can be embedded as a step of more sophisticated distributed algorithm as it is the case for the Distributed Kalman filter [80] and the Distributed Alternating Least Squares algorithm [77]. Obviously, asymptotic convergence is not suitable for these kinds of distributed methods. Even though, speed convergence of consensus algorithm have been explored in [78] and [91] with the goal to derive fast consensus algorithms, running standard consensus in finite-time constitute a source of errors not easily quantifiable. Sometimes, bounds can be derived. Therefore, it is interesting to address the question of exact consensus in finite-time.
For time-invariant network topologies and in the perfect information exchange case, i.e. without channel noise nor quantization, we have shown that the finite-time average consensus problem can be solved as a matrix factorization problem with joint diagonalizable matrices depending on the Graph Laplacian eigenvalues [38], [48]. Moreover, the number of iterations is equal to the number of distinct nonzero eigenvalues of the graph Laplacian matrix. Then, by periodically restarting the consensus algorithm, we have also shown that, in the noisy case, exact average consensus can be achieved asymptotically.

- Quadratic indices for performance evaluation of consensus algorithms
  **Participants:** F. Garin [Contact person], S. Zampieri [Università di Padova], E. Lovisari [Università di Padova].

  Traditional analysis of linear average-consensus algorithms studies, for a given communication graph, the convergence rate, given by the essential spectral radius of the transition matrix (i.e., the second largest eigenvalues' modulus). For many graph families, such analysis predicts a performance which degrades when the number of agents grows, basically because spreading information across a larger graph requires a longer time. However, when considering other well-known quadratic performance indices (involving all the eigenvalues of the transition matrix), the scaling law with respect to the number of agents can be different. This is consistent with the fact that, in many applications, for example in estimation problems, it is natural to expect that a larger number of cooperating agents has a positive, not a negative effect on performance. It is natural to use a different performance measure when the algorithm is used for different purposes, e.g., within a distributed estimation or control algorithm. Examples of various relevant costs can be found in the book chapter [50] and in the references therein.
  We are interested in evaluating the effect of the topology of the communication graph on performance, in particular for large-scale graphs. Motivated by the study of wireless sensor networks, our main objective is to understand the limitations which arise when agents are limited to truly local interactions, i.e., the neighborhoods are determined by being 'near' in a geometric (Euclidean) way, differently from graphs with few but possibly 'distant' connections, such as in small world models. At first [18] we consider graphs which are regular lattices (infinite lattices, or grids on tori, or grids on hyper-cubes), which are examples of geometrically local interactions, but also have a very rich structure: their symmetries allow to exploit powerful algebraic tools, such as the discrete Fourier transform over rings, to compute their eigenvalues, and then find bounds on the associated costs. Then, we extend the results to a more general class of graphs, thus showing that the behavior of lattices is mainly due to the local nature of interactions and not to the symmetries. To do so, we exploit the analogy between reversible Markov chains and resistive electrical networks. This latter work is part of the Ph.D. thesis of E. Lovisari at University of Padova, Italy.

- Distributed averaging over digital noisy networks
  **Participants:** F. Garin [Contact person], R. Carli [Università di Padova], G. Como [MIT], P. Frasca [Politecnico di Torino].

We study iterative distributed averaging algorithms for networks whose nodes can communicate through memoryless erasure broadcast channels. In order to compare the performance of different algorithms, we define suitable complexity measures, which account for the number of channel transmissions (communication complexity), and, respectively, of in-node computations (computational complexity) required to achieve a desired precision. These performance measures are particularly relevant, as they allow for directly estimating the energy consumption of such distributed computation systems, as well as their time-complexity.
The algorithms we propose combine the classical iterative linear consensus algorithm (where at each iteration, each agent receives the states of its neighbors and takes a suitable convex combination of them), with source-channel coding schemes for the reliable transmission of real numbers on noisy channels. Our algorithms involve a sequence of transmission phases, of increasing duration, in which the agents attempt to broadcast their state, i.e. their current estimate of the global average, to their neighbors, alternated to averaging steps, in which the agents' states are updated. These algorithms are fully distributed, and they do not require the agents to have any global knowledge of the network structure or size. Our main result shows that such algorithms drive the agents to state agreement (consensus) which can be made arbitrarily close to the true average. The number of channel transmissions and in-node computations is shown to grow at most poly-logarithmically in the desired precision. We also show how communication feedback, when available, allows one to modify the algorithms, achieving asymptotic average consensus (i.e., state agreement on the average of the initial observations), and reducing the computational and communication complexities. This work is presented in the paper [15]. In the paper [22], we present and analyze a modified algorithm, which can be used when source coding (compression) and channel coding (error correction) are performed by two separate encoders. Such algorithm takes into the account the fact that, even without any channel feedback, the part of the error which is due to lossy compression and not to channel noise is perfectly known by the transmitter, and a compensation can be introduced, thus improving performance.

- Distributed Consensus algorithms
  **Participant:** A. Seuret [Contact person].

  Concerning this problem, we address the classical issues of the stability analysis of consensus algorithm in continuous-time. The objective of the present work is to show that the performances classical consensus algorithms can be improved using an appropriate memory of the controlled state. We want to design a novel type of consensus algorithm which uses not only the current state of the algorithm but also a sampled version of it. The key problems are here the design of the best parameters, i.e., the sampling period and the ratio between the contributions of the current and the sampled states. It has to be noticed that a usual intuition is to say that using past values of the state a reduction of performances or to instability. However, our contributions show that this is not always in single and double integrator consensus algorithms [41]. These contributions is based on an LMI framework and based on algebraic communication matrix structure. The efficiency of the method is tested for different network communication schemes.

### *6.2.4. Distributed real-time Simulation of numerical models*

**Participants:** D. Simon [Contact person], A. Ben Khaled [IFPEN], M. Ben Gaid [IFPEN].

To allow real-time simulation of high fidelity engine models, different techniques have to be applied in order to fulfill the real-time constraints. Real-time simulation involves trade-offs between several aspects, such as real-time constraints, models computational complexity and integration accuracy. Traditionally HIL designers consider that every step of the simulation must be real-time and deterministic, leading to strongly synchronized systems, at the cost of ineffective computation burdens. It has been shown that adequately splitting the plant's model into weakly synchronized sub-systems allows for efficiently using variable steps numerical integrators, simulation speed-ups and subsequent effective parallel versions of HIL systems [25].

## 6.3. Stability and control design of asynchronous interconnected systems

### *6.3.1. New approaches for stability conditions design*

- Stability for asynchronous sampled data systems
  **Participants:** A. Seuret [Contact person], C. Briat [KTH], J. Gomès Da Silva Jr. [UFRGS], W. Jiang, M. M. Peet [Illinois Institute of Technology].

  During the last year an important effort has been devoted to controlled systems under communication constraints. In particular a novel approach to assess stability of continuous linear systems with sampled-data inputs has been provided for the first time in [21]. The main contribution of this article is to make the bridge between the discrete-time and the continuous-time approaches to ensure stability of the closed loop system. The interest of the method remains in the application of the discrete-time Lyapunov theorem using the continuous-time model without introducing exponential. This method suggests the introduction of particular types of functionals of several shapes: using an adaptation of classical time-delay functionals [21]; using a discretization method [26]; or using SOS [44].
  Then extensions to uncertain systems, time-varying parameter systems [21]; or non linear systems (for instance with saturations [36], [43]) become straightforward in comparison to the discrete-time approaches. The stability conditions are expressed in terms of linear matrix inequalities. Sufficient conditions for asymptotic and exponential stability are provided dealing with synchronous and asynchronous samplings and uncertain systems. An additional stability analysis is provided for the cases of multiple sampling periods and packet losses in [21]. Moreover this method has also been extended to the case of sampled-data systems with additional input delay [42], [46] and to the case of impulsive systems (several papers are submitted on this topic, for example [65]).

- Stability of control under weakened real-time constraints
  **Participants:** D. Simon [Contact person], A. Seuret, P. Andrianiaina [AIRBUS].

  A weakened implementation scheme for real-time feedback controllers is proposed to reduce the conservatism due to traditional worst-cases considerations. To save wasted computing resources, new real-time scheduling scenarios allowed for reducing the time slots allocated to control tasks below the value of the Worst Case Execution Time which is traditionally used to implement embedded control software. The stability of the control system under occasional deadlines miss is assessed using robustness arguments, using Lyapunov-Krasovskii functionals and LMIs solving based on [46]. The methodology has been successfully assessed for a fighter aircraft pitch controller, which show that the stability of the plant can be kept (and even improved) using the new scheduling schemes using less computing resources than traditional implementations [24], [63].

### *6.3.2. Control for asynchronous sampled data systems*

- Control architecture and tools
  **Participants:** D. Simon [Contact person], R. Pissard [SED], S. Arias [SED].

  During the development of control systems, hardware-in-the-loop that is showed in Fig. 6 takes place between design level simulations and costly experiments with the real plant. Using the prototype of ORCCAD V4 several HIL real-time simulators have been set up. These simulators combine multi-threaded/multi-rate real-time controllers running control algorithms synchronized with a variable step numerical integrator running a model of the plant [49]. These simulators have been further used to implement and test several kind of feedback/flexible scheduling schemes related to the FeedNetBack project, in particular real-time controllers subject to (m,k)-firm scheduling, Kalman filters modified to account for data loss and varying sampling controllers [62]. Finally a collaboration with SARDES about the integration of discrete (logical) control loops on top of continuous control tasks has been carried on. In this architecture ORCCAD is used to design the low level continuous controllers while the reactive parts are designed and synthesized using the BZR language [23].

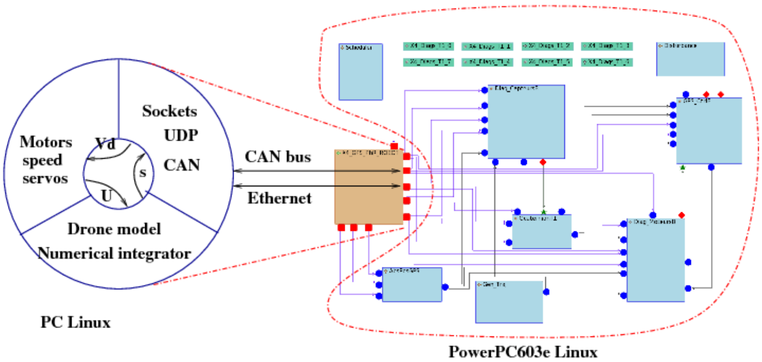


*Figure 6. Hardware-in-the-loop.*

- Event-based control algorithms
 **Participants:** A. Seuret [Contact person], N. Marchand [Contact person], S. Durand.

 Asynchronicity is becoming more and more meaningful in modern control architectures and some new control strategies are being developed by some research teams in the world. The principle of these control laws is to compute a new control signal only when some event occur, where a event characterizes a change in the system and therefore a need for a new control. These approaches are supposed to reduce the number of times the control is computed (and consequently the CPU utilization) and to remove the real-time hard constraint on the computational system. Some works around this domain have been proposed by some members of the NeCS team.
 In [45], one may look at the problem of reducing the amount of information to be sent to the actuators through the Network. Indeed the controller may be able to trigger the information to be sent. The main idea is to let the controller decide if the system needs an update of its control input. This class of control algorithms is called event-triggered. An algorithm is suggested to sample the control input based on the behavior of a Lyapunov-like function in [45]. This algorithm is event-triggered since the Lyapunov-like function directly depends on the state of the systems.
 In [69] and [73], we firstly proposed to remove the safety limit condition introduced by K-E. Årzén in his event-based PID controller [93]. In this paper, the control signal is updated only when required from a performance point of view, that is when the measurement crosses a given level. Årzén also suggested to enforce an event when the sampling interval achieves a given maximal amount of time. This safety limit was added to prevent the system to be sampled less than what Shannon theorem requires but, in fact, we showed that the Shannon sampling condition is no more consistent in the context of event-based systems. Moreover, a practical implementation of a cruise control mechanism on a small radio-controlled vehicle was recently suggested [34]. Moreover, we are interested on updating the control signal only when required from a stability point of view. Such a solution consists for instance in enforcing an event when a Lyapunov function crosses a given level. Based on the seminal work from M. Velasco in [90], we suggested a simple Lyapunov sampling in [33].

- Control with adaptive sampling
 **Participants:** D. Simon [Contact person], O. Sename, E. Roche.

 Control and real-time computing have been associated for a long time, for the control of industrial plants and in embedded or mobile systems, e.g. automotive and robotics. However both parts, control and computing, are often designed with poor interaction and mutual understanding. We propose here an integrated control and scheduling co-design approach, where closing the loop between the control performance and the computing activity is promising for both adaptivity and robustness issues. We

developed during the last years a variable sampling control methodology based on the LPV (Linear Parameter Varying) framework and $H_\infty$ control synthesis, where the sampling interval is used as a known and controlled variable [8]. Few assumptions about sampling are needed for this control design : the main point is that the control interval is known and lies between the predefined bounds $[h_{min}; h_{max}]$ , whatever the origin of the control interval variations, its speed and its frequency. Another approach is proposed now to design sampling varying gain-scheduled controller for LPV systems, based on the Linear Fractional Representation (LFR). This method has already been studied concerning the synthesis of discrete-time gain-scheduled controller, depending only on the sampling period. The method has been extended to deal with the design of a gain scheduled LFT controller w.r.t the sampling interval and w.r.t system's parameters, given a discrete-time Linear Fractional Representation (LFR) of the LPV varying sampling model [13]. The approach comes from the robust control theory and consists in separating the LTI part $P$ (not depending on the set of parameters) from the varying part $\Delta$ (parameters or uncertainties), as shown on Fig. 7. The matrix $\Delta$ represents the influence of the set of parameters $\rho(.)$ on the plant. From this model, a gain scheduled controller can be computed, depending on the same set of parameters $\Delta$, or a subset of $\Delta$. The LFT approach proposed in [83] has been extended to set a LFR model that accounts for system and sampling parameters. In that case the uncertainty matrix is as depicted in Fig. 7 on the right, where $\delta$ is the deviation of the sampling interval w.r.t. the nominal sampling rate and $\Delta$ account for the plant's uncertainty. A controller is then synthesized using the $H_\infty$ framework, where weighting functions allow to shape the control system's response [82].
In the framework of the FeedNetBack IST project, the LFR formulation previously presented is applied to an Autonomous Underwater Vehicle (AUV) for the control of its altitude $z$ [40]. The global control structure is presented on Fig. 8. To control the altitude, two controllers are considered ($\widehat{K}_z(\delta)$ and $\widehat{K}_\theta(\delta, \rho)$) based on two models ($\widehat{G}_z(\delta)$ and $\widehat{G}_\theta(\delta, \rho)$). The LFR formulation is used here to keep some varying parameters into the model formulation. Indeed, in previous works, the limits of a simple linearization around a fixed equilibrium point have appeared. When the pitch angle is too far from 0 (the value chosen for $\theta$ at equilibrium), the linearized model becomes too different from the linearized one, which leads to bad performances. The $\Delta$ block contains the varying part of the model, which depends on the linearization point ($\theta_{eq}$). The two considered varying parameters are $\rho_1 = cos(\theta_{eq})$ and $\rho_2 = sin(\theta_{eq})$. The model is then discretized and the sampling period is added to the $\Delta$ parameter block. Compared with the previous approach using a linearized plant model, the new one shows (in simulation) improved altitude tracking and a better utilization of the available range of the actuators [82].

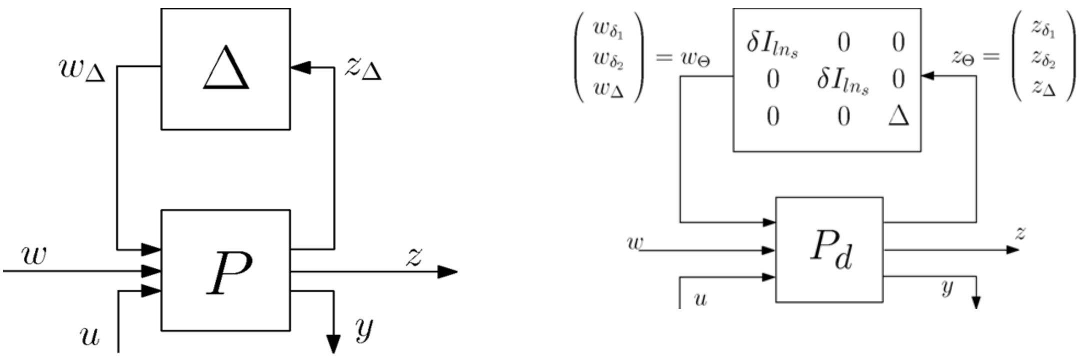


*Figure 7. System under LFT form.*

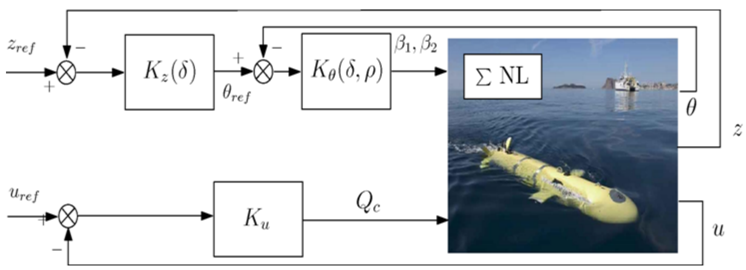


*Figure 8. Global control structure.*

## 6.4. Vehicular transportation systems

### *6.4.1. Traffic modelling, estimation and control*

**Participants:** C. Canudas de Wit [Contact person], C. Irinel-Constantin [CRAN], D. Pisarski, L. Leon Ojeda.

This part is related to the developed work within the Network of Excellence HYCON2 (Highly-Complex and Networked Control Systems). It interested to problems of modelling, estimation and control in traffic.
In [81], the problem of equilibrium sets for the Cell Transmission Model is studied. The objective is to design the homogeneous distribution of density on the freeway, where the input flows are the decision parameters to be determined. For the proper design of the balanced density the extensive analysis on the structures of equilibria is crucial. The analysis is carried out for the two different cases, where all sections of the freeway are assumed to be free or congested, respectively. The necessary conditions for the existence of balanced equilibria are formulated. These conditions show, that the key for the design of the balanced states may be the variable speed limiting, which strictly cooperates with the ramp metering. The computational algorithm for the input flows in case of free balance is proposed. In order to illustrate the results, the numerical example is provided.
In [39], the authors are interested to the highway traffic model-based density estimation. A strategy is proposed for real-time density estimation for traffic networks. To this aim, we introduced a deterministic constrained macroscopic model which reduce the number of possible affine dynamics of the system and preserve the number of vehicles in the network. This model is used to recover the state of the traffic network and precisely localize the eventual congestion front. The state of the network is recovered using what we call forward/backward observers. We pointed out that during unobservable modes the estimation error is preserved due to vehicle conservation law. Numerical simulations show the efficiency of the proposed strategy.
In [30], the problem of front congestions control is treated. For this, we have introduced a new traffic lumped model with only two cells (one free, and another congested) the cells have variable length, and a variation law for the front congestion completes the 3-dimensional model. In opposition to fixed-length cell models that are commonly represented by a set of linear state-dependent switching systems, our model results in a lower dimensional nonlinear system which solutions are continuous. Based on this model, we have designed a “best-effort” control strategy using variable speed limits. The notion of best effort control is here linked to the physical variable speed limit constraints which limits its size and as well as its rate variation. This results in a relative simple control in closed-form that can be implemented by using only information about the front congestion location.

Other work is under development and is related to the traffic show case application and the achievements reached that correspond to the operation of the freeway network around the Grenoble area (Grenoble South Ring). We started by designing the general network architecture, after specifying sensors and actuators locations along the highway and finally setting the platform of an interface between Matlab and our micro simulator "Aimsun". We have also carrying out some simulations from a real life application on Grenoble South ring of a deterministic state estimation technique. Using constrained macroscopic model which in fact reduces the number of dynamic states and preserves the conservation law (number of vehicles in the network).

### 6.4.2. Vehicle control

- Tele-operated control
  **Participants:** C. Canudas de Wit [Contact person], W. Jiang, J. Dumon, O. Sename.

  A mathematical driver model in the spatial equation form has been introduced for analysis of drivers' behavior [31]. In the model, a previewed distance is taken into account. First, optimal control is applied. For the ideal case without driver's reaction delay concerned, for both long distance preview and shorter one, the vehicle tracks well the path. Whereas, when time-delay added into the system, too short preview distance cause the instability of the system. The simulation result corresponds with the real driving experience. Then, Lyapunov-Krasovskii functional approach is applied deal with stability problem with the driver's delay. In this case, when the delay becomes greater, the longer preview distance will be needed. The average derivation of the steering input is calculated for different preview distance as well as the time-delay cases, which well verifies our driver model. The main contribution of this model is that the preview effect only depends on the path information and it does not affected by the vehicle speed, so the result is more neutral
- Electric Power Steering Systems
  **Participants:** C. Canudas de Wit [Contact person], V. Ciarla, J. Tordesillas Illàn [UJF].

  This part presents several aspects of modeling, observation and control towards a new generation of Electrical Power Steering(EPS) systems [47]. In particular we design an optimal control to reject oscillations of the steering column, then we device a new observer to estimate the internal state variables of the steering column, the driver applied torque (steering wheel torque), and the load torque (tire/ground contact friction). Finally, we also revisited the LuGre tire dynamic friction model by improving the transient behavior between the sticking phases and the dynamic ones. Simulation of the proposed control and observer are shown at the end of the paper using the improved LuGre-tire friction model. Index Terms—Electric Power Steering systems (EPSs), LQ control, LuGre friction model, observer.

## 6.5. Energy-aware control of systems on chip

**Participants:** N. Marchand [Contact person], S. Durand.

Achieving a good compromise between computing power and energy consumption is one of the challenges in embedded architectures of the future. This management is especially difficult for $45\,nm$ or $32\,nm$ known to be at the limit of the scalability, i.e. with a high process variability. This is a key point in the ARAVIS project. Automatic control loops have therefore to be designed to minimize the energy consumption still making the performance fit the requirement in a context of highly technological uncertainties of the chip. This issue is notably discussed in [92]. Finally, the main objective is to dynamically control the computing activity and the energy consumption using the voltage and the frequency according to the requirements of the operating system. In this way, a robust control law was developed in [72] and [32] in order to minimize the high voltage running time with a predictive technique, i.e. to minimize the energy consumption while ensuring good computational performance. This control was initially done for one node (i.e. a processor) but in ARAVIS SoC, the chip is composed of several clusters with several nodes each (see Fig. 9). Thus, the energy controller has to manage the voltage level (one voltage domain by cluster) and the frequency for all nodes: a maximal frequency is performed for critical node and then a ratio of this frequency could be apply for the other nodes. Thus, a multicore control strategy with low computational needs was also proposed [71]. This work yields two patents: the first one for the monocore case [70] and the second one for the multicore case [74].

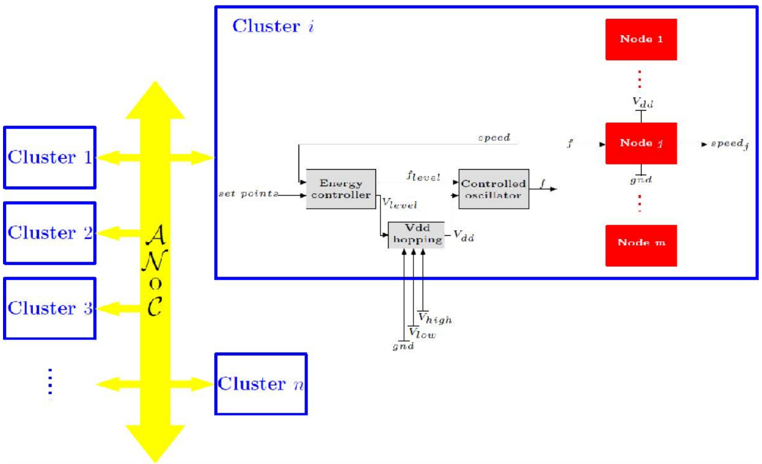


*Figure 9. Architecture du SoC ARAVIS.*

# 7. Contracts and Grants with Industry

## 7.1. Grants and contracts with Industry

### *7.1.1. IFP*

Accompanying contract with IFPEN (IFP Energies Nouvelles), in the framework of the PhD grant of A. Ben Khaled. The thesis explores new architectures and flexible scheduling methods to enhance the trade-off between the integration accuracy and the simulation speed of distributed real-time (hardware-in-the-loop) simulators, in particular in the framework of automotive power-trains [25].

### *7.1.2. AIRBUS*

Accompanying contract with AIRBUS in the framework of the CIFRE PhD grant of P. Andrianiaina. The goal of this PhD thesis is to study flexible implementation methods for real-time controllers, aimed at reducing the conservatism induced by the current approach purely based on worst case considerations [24], [63], [51].

## 7.2. Technology transfer: start-up Karrus

The NeCS team is continuing its activity in road traffic modeling and control. The expected scientific contribution of NeCS in this field concerns the development of new estimation prediction and identification algorithms based on the measurements collected through sensor networks installed on freeways. The team study also the problems of time-to destination and control algorithms for ramp metering. The team is currently setting up a consortium with local authorities involved in traffic management to build to demonstrator called GTL for Grenoble Traffic Lab. One target of this activity is to transfer part of the developed technology to a start-up named Karrus and led by Denis Jacquet (http://www.karrus.fr/). The start-up was created in January 2010.

# 8. Partnerships and Cooperations

## 8.1. Regional Initiatives

### 8.1.1. Pôle de compétitivité Minalogic/ARAVIS

ARAVIS (Architecture reconfigurable et asynchrone intégrée sur puce) is a project sponsored by the Minalogic Pole, started in October 2007 for 3 years (http://www.minalogic.com/PAR_TPL_IDENTIFIANT/903/TPL_CODE/TPL_PROJET/31-recherche.htm). The project has been extended to december 2011. The innovation key deals with bringing architecture and design solutions to calculation platform problems for embedded systems at the 32-nm and 22-nm scales by combining three core technologies: - ST's DSPfacbric coarse-grain structure, which aims to implement several dozen identical data paths on the same System-on-Chip (SoC) and to reconfigure them according to the needs of the application - Techniques based on asynchronous logic (in other words, without a clock) to resolve issues arising from the variability of physical characteristics within each processing node - Advanced automatic techniques for dynamic power and activity management according to oftencontradictory demands such as low voltage and calculation power. The project is headed by STMicroelectronics, the other partners are CEA-Leti, TIMA laboratory and the SARDES and NECS teams at INRIA. Previous works on a high-performance controller development for a novel discrete DVS converter were done within this project [14].

## 8.2. National Initiatives

### 8.2.1. ANR CONNECT

CONNECT (**CON**trol of **NE**tworked **C**ooperative sys**T**ems) is a project funded by the ANR (National Research agency). The project deals with the problem of controlling multi-agent systems, i.e. systems composed of several sub-systems interconnected between them by an heterogeneous wireless communication network. In particular the project target the control of a cluster of agents composed of autonomous underwater vehicles and marine surface vessels. The main challenge here is to learn how to design collaborative controllers accounting for marine communication constraint, but also on the possibility to share computational resources during the system operation. Questions on control architecture in terms of the level of control distribution and control coordination are addressed as well. A generic and open simulation tool able to integrate the various kinds of component's models found in such a networked multi-agents system are developed and used to assess the related theoretical studies. Potential missions that can be effectuated by this control approach include: 1) Undersea mapping and monitoring via fleets of autonomous underwater vehicles (AUVs), 2) Relocate an aircraft's black box after crashing into the sea, 3) Detection of industrial or military garbage or mines and 4) Source detection by gradient search (fresh water, chemical source, methane vent,. . . ). The partners are the NECS team, Ifremer robotics lab. and the ROBOSOFT and Prolexia companies. It started in May 2007, for a duration of 3 and a half years. The project end was in March 2011. More information can be found on-line: http://www.gipsa-lab.inpg.fr/projet/connect/.

### 8.2.2. ANR VOLHAND

VOLHAND (**VOL**ant pour personne âgée et/ou **HAND**icapée) is a project funded by the ANR (National Research agency). This project, started in October 2009, is a result of collaboration between C. Canudas de Wit and Franck Quaine/Violaine Cahouët (from the biomechanical team of GIPSA-Lab). The project aims at developing a new generation of Electrical power-assisted steering specifically designed for disabled and aged people. Our contribution is to work out new assisted laws that accomodate to the specific mechanical characteristics of this particular driver population. The consortium is composed by: LAMIH, CHRU, Fondation Hopale, GIPSA-Lab, INRETS and JTEKT. More information can be found on-line: http://www.univ-valenciennes.fr/volhand/.

## 8.3. European Initiatives

### 8.3.1. FeedNetBack

The FEEDNETBACK proposal has been accepted as a STREP project at the FP7-ICT-2007-2 call in October 2007, for a duration of three years and will end in January 2012. It is coordinated by C. Canudas de Wit and gathers researchers from academia (INRIA-NeCS, ETH Zurich, Universidad de Sevilla, KTH Stockholm, Universita di Padova) and from industry (Ifremer, Videotec and OMG). The main objective of the FeedNetBack project is to generate a rigorous co-design framework that integrates architectural constraints and performance trade-offs from control, communication, computation, complexity and energy management. The goal is to master complexity, temporal and spatial uncertainties such as delays and bandwidth in communications and node availability. This approach enabled the development of more efficient, robust and affordable networked control systems that scale and adapt with changing application demands. The project extend the current scientific state-of-the-art in networked control and develop a set of software tools to support the co-design framework. To demonstrate the potential and limitations of the new technology, FeedNetBack applies it on two industrial test cases of realistic complexity and scale: underwater inspection systems based on fleets of Autonomous Underwater Vehicles (AUVs), and surveillance systems using a network of smart cameras. The control component is essential in both test cases as they require cooperation of distributed objects to achieve a common goal (http://feednetback.eu/). Specific issues are addressed in the project:

- Heterogeneity: The sensor hardware and the communication means may be of different natures (different noises, bandwidths, resolution characteristics, etc.).
- Mobility: Sensor location may not be fixed. Dynamic location of sensors will lead to varying topologies.
- Resource management: The energy and computation capabilities of each node are generally limited.
- Scalability: Wireless sensor networks may comprise hundreds or thousands of nodes. It is therefore crucial that the complexity of the design procedures and the resulting controllers scale slowly with the number of nodes.
- Asynchrony: Information exchange between sensor/control units may not be synchronous in time.

Since in NCS the goal is to ensure satisfactory performance of the overall closed loop system, these problems are treated holistically through sets of performance constraints. The co-design framework aims at controlling more complex systems with a fraction of the effort, while increasing availability and reliability. The framework will enable application developers, programmers and systems integrators to fully use the potential of networked control in a wide set of industrial domains. Examples of areas where an impact is expected are the fields of factory automation, public infrastructure safety and security, transport and building maintenance. New technologies have been developed and applied in FeedNetBack to areas of society where they protect the environment and improve people's safety, security and ultimately quality of life.

### *8.3.2. HYCON2*

HYCON2 (Highly-Complex and Networked Control Systems) is a Network of Excellence, within the European Union's FP7. It has started on September 2010, for a duration of three years. Coordinated by Françoise Lamnabhi-Lagarrigue (L2S-CNRS), it involves 26 academic institutions from all over Europe. ICT developments both enable and enforce large-scale, highly-connected systems in society and industry, but knowledge to cope with these emerging systems is still lacking. HYCON2 will stimulate and establish the long-term integration of the European research community, leading institutions and industry in the strategic field of control of complex, large-scale, and networked dynamical systems. HYCON2 will assess and coordinate basic and applied research, from fundamental analytical properties of complex systems to control design methodologies with networking, self-organizing and system-wide coordination. HYCON2 has identified several applications domains to motivate, integrate, and evaluate research in networked control. These domains are ground and aerospace transportation, electrical power networks, process industries, and biological and medical systems. Benchmarking will serve as a tool for testing and evaluating the technologies developed in HYCON2 and for stimulating and enforcing excellence by the identification and adoption of best practices. In particular, two show-case applications corresponding to real-world problems have been selected in order to demonstrate the applicability of networked control and the need for research in control. The proposed research, integration and dissemination program will make Europe both the prominent scientific and the industrial leader in the area

of highly complex and networked control systems, therefore posing Europe in an extraordinary position to exploit their impact in economy and society.
The NeCS team is mainly involved in the first show case application, which corresponds to the operation of the **freeway network around the Grenoble area**. The recent advent of new vehicle sensing technologies provides an opportunity for innovative control applications in traffic management. The Grenoble Traffic Lab (GTL) initiative, lead by the NeCS team, has the ambition to equip massively the Grenoble south beltway with wireless magnetometers. The availability of such a reliable sensor network, designed primarily with control applications in mind, will allow to see control systems used in the field of freeway management. Control systems in road transportation are primarily involved in the management of traffic lights in urban (city corridors), and inter-urban sectors (rings highways). The target of most of the efforts in the domain is to improve the freeway efficient in an equal way to all drivers. The goal of this show case is to provide a rich set of field traffic data to the control community in order to test their algorithms on a practical real-world problem. These data will be available through a web server administered by INRIA along with all the maps describing finely the freeway under study. Historical and real time data will be available. All these data wiLL be ready for experiments and the outcomes can be provided to the road operators to judge the relevance and efficiency of the results for operational use.

### 8.3.3. TeMP

TeMP (Tensor-based Information modelling and Processing) is a project funded in the framework of the French-Brazilian bilateral collaboration program (FUNCAP-INRIA). It started from August 2011 for a duration of two years and is coordinated for the French part by A. Kibangou. This project aims to study, analyze, propose and evaluate new models and techniques for digital communication systems using tensors and multilinear algebra tools, through in-depth theoretical analysis of mathematical models, optimization algorithms, and computational simulations. Indeed, new models should be developed for generalizing existing tensor models in order to allow the modeling of a wider class of communication systems for more realistic propagation channels including the cooperation among multiple nodes of a communication network (users or sensors). Due to dynamic change of parameters, tensor-based filtering algorithms need to be developed for information retrieval systems in cooperative communication. These algorithms should be distributed for avoiding network vulnerability and for a better management of computation and storage resources.

## 8.4. National and International Initiatives

### 8.4.1. INRIA Associate Teams

- The NeCS team is a partner in the Sensas A.D.T. (started in December 2010), where it is involved in the coordinated control of a networked swarm of mobile robots.

### 8.4.2. INRIA National and International Partners

Long term collaboration does exist with the University of Sevilla along several different topics including: coding and control co-design, Power control in NCS, energy-aware control in SoC, and control of DC/AC converters. Scientific collaborations inside the IST FeedNetBack project have been initialized with ETH Zurich and University of Sevilla about the integration of control and scheduling on distributed architectures, in particular focusing on the robustness and predictive control point of views. The ANR SafeNecs project provided support and collaboration along the three past years with teams from both the computing side (LORIA Trio team about control and (m,k)-firm scheduling) and from the fault tolerant control side (CRAN Nancy and GIPSA-LAB, about the integration of real-time control, diagnosis and flexible scheduling). Strong collaborations have been established with KTH (Stockholm), ETH (Zurich), University of Sevilla and Padova as core partners of the FeedNetBack European project.

- C. Canudas de Wit has collaborations with University of Sevilla, Spain (F. Gomez-Estern, F. R. Rubio, F. Gordillo, J. Aracil).

- A. Seuret has collaborations with LAGIS, Lille (J.-P. Richard), Leicester University, UK (C. Edwards), University of Kent, UK (S.K. Spurgeon), Tel Aviv University, Israel (E. Fridman), Universidade Federal do Rio Grande do Sul, Brasil (J.M. Gomes da Silva Jr.), KTH, Sweden (K.H. Johansson, D.V. Dimarogonas, C. Briat), Illinois Institute of Technology, USA (M.M. Peet) and Cinevstav, Mexico (S. Mondié).
- D. Simon spent one week in the Department of Automatic Control and Systems Engineering, University of Sevilla (25-29/04/2011), working with David Muñoz on the integration of MPC based schedulers and LPV varying sampling control loops.
- A. Kibangou has collaborations with I3S, Nice (G. Favier) and Universidade Federal do Ceara, Brazil (A.L.F. De Almeida).
- F. Garin has collaborations with Università di Padova, Italy (R. Carli, E. Lovisari, S. Zampieri) and Politecnico di Torino, Italy (P. Frasca, F. Fagnani) and with MIT, USA (G. Como).
- H. Fourati has started a new collaboration with the Kazakhstan National Technical University (KazNTU). He curretly co-advises with Pr. Syzdikov Dastan Jacanovich in KazNTU, Zarina Samigulina PhD student in KazNTU. He has also some collaborations with CReSTIC/University of Reims Champagne Ardenne (N. Manamanni) and DEPE/IPHC/University of Strasbourg (Y. Handrich).

### *8.4.3. Visits of International Scientists*

- Dr. Daniel Quevedo from the University of Newcastle (Australia) has visited the NeCS team for one week in September 2011.
- Enrico Lovisari, PhD student at Università di Padova has visited the NeCS team for one week in July 2011.
- Fabio Gomez-Estern from University of Sevilla has visited the NeCS team for 3 weeks in January 2011.
- Pr. Sabine Mondie from PCinvestav, Mexico has visited the NeCS team in September 2011.
- Pr. Valter Leite from CEFET–MG, Campus Divinopolis, Brasil has visited the NeCS team during 2011.

# 9. Dissemination

## 9.1. Animation of the scientific community

- C. Canudas de Wit has participated to several concertation meetings in the CORDIS reseach program at the ITC department in the EU. He participated as evaluator in the FP7 program “Factories of the Future": FP7-2010-NMP-ICT-FoF, and as reviewer of EU projects in the FP6 program on Embedded Systems and Control. He was nominated at the Board of Governors of the IEEE Control System Society for 2011, and he has been elected for 3 more years. He is also the responsible of joint activites between the IEEE-CSC and the EUCA (Europeen Control Associated) where he belongs to the steering board.
- F. Garin has been a member of the recruiting committee, held in May 2011, for an Associate Professor position (poste de Maître de Conférences) in IUT 1 (University Joseph Fourier, Grenoble) and the Automatic Control Departement of GIPSA-LAB.
  She organized the 3$^{rd}$ annual Consortium Meeting of the FeedNetBack European project, held at INRIA in Montbonnot, on October 11-12$^{th}$ 2011.
  She has been a peer-reviewer for international journals (IEEE Trans. Automatic Control, IEEE Trans. Inform. Theory, Automatica, Systems and Control Letters) and conferences (CDC-ECC 2011, ACC 2011, ACC 2012).

- A. Kibangou was a member of the Technical Program Committee of the European Signal Processing Conference (EUSIPCO) 2011. For the Carnot Insitute LSI, he was member of the “Sensor Networks Initiative" of the ICT-MNT Carnot alliance. In this framework, he was a contributor to a white book devoted to the vision of the ICT-MNT Carnot alliance on Internet of things. He was member of two selection committees for University Joseph Fourier in 2011.
He serves as a reviewer for the following international journals: Automatica, IEEE Transactions on Control Systems and Technology, Signal Processing (Elsevier), Electronics Letters, Int. J. of Adaptive control and Signal Processing, and System control letters. Locally, he is the organizer of seminars for the Control Department of GIPSA-LAB.
- A. Seuret is co-animator of the “Time-delay System" group (GDR SAR) since March 2008. He is leader of a Workpackage of the European Project FeedNetBack. He is general chair of the Summer School on Automatic Control of Grenoble since 2010.
He is also reviewer for the major Journals and Conferences of the field. Among them, there are journals (IEEE Trans. on Automatic Control, Automatica, System Control and Letter, International Journal of Systems Science) and conferences (Conference on Decision and Control (CDC), American Control Conference (ACC), IFAC Workshops on Robust Control (ROCOND) and on Time Delay Systems (TDS)).
- D. Simon is member of the RTNS’11 (international conference on Real Time and Network Systems) and CIFA’12 (Conference Internationale Francophone d’Automatique) program committees. He has been also member of the scientific and organization committees of CAR’11 (Control Architectures for Robots) at Montbonnot, Grenoble. He served as reviewer for the PhD of H. H. Nejad (July 2011, CRAN, Nancy), C. Faure (October 2011, IFPEN and ISIEE, Paris), J. B Chaudron (December 2011, Onera and ISAE, Toulouse) and examiner for the PhD defense of S. Durand (January 2011, Grenoble INP), F. Felicioni (January 2011, Loria Nancy and University Rosario, Argentina) and E. Roche (October, Grenoble INP). Involvement and talks within the API (Automatique Pour l’Informatique) PEPS headed by E. Rutten (SARDES).
He has been also a peer-reviewer for MSR’11 (Modélisation des Systèmes Réactifs) and MED’11 (Mediterranean Conference on Control and Automation) conferences.
- H. Fourati has been a peer-reviewer for international journals (IEEE Sensors Journal, IEEE/ASME Transactions on Mechatronics).

## 9.2. Teaching

### *9.2.1. Courses*

- A. Kibangou
DUT: Mathematics, 20h, Licence 2, IUT 1 (GEII 1), University Joseph Fourrier, France.
DUT: Automatic Control, 46h, Licence 2, IUT 1 (GEII 1), University Joseph Fourrier, France.
He is in charge of the Automatic control Lab of the GEII 1 department at IUT 1 of Grenoble.
- A. Seuret
MASTER: Automatic Control, 40h, MASTER 1 and 2, Grenoble INP, France.
He organizes the 32$^{th}$ International Summer School of GIPSA-Lab on Automatic Control, September, 12-16, 2011, Grenoble, France.
The Summer School was on Robust Control and Linear Parameter Varying approaches: Application to vehicles dynamics, with the scientific direction of O. Sename (Grenoble INP), see http://www.gipsa-lab.inpg.fr/summerschool/auto2011/.
- H. Fourati
DUT: Informatique Indutrielle, 24h, Licence 1, IUT 1 (GEII2), University Joseph Fourrier, France.
DUT: Automatismes industriels et réseaux : réseaux, 90h, Licence 1 et 2, IUT 1 (GEII2), University Joseph Fourrier, France.

### *9.2.2. Advising*

Postdocs:

- Alireza Esna Ashari Esfahani, (INRIA, chaire Schneider, Nov. 2011 - Oct. 2012), co-advised by F. Garin and A. Kibangou.
- Alireza Farhadi, (INRIA, Aravis project, Jan. 2010 - Aug. 2011), advised by C. Canudas de Wit.
- Sylvain Durand, (INRIA, ARAVIS project/CRI PILSI, Jan. 2011 - Dec. 2011), advised by N. Marchand.

PhD students in progress:

- Patrick Jocelyn Andrianiaina, Robust control under weakend realtime constraints, Grenoble INP, Avr. 2009 - Mar. 2012, co-advised by D. Simon and A. Seuret.
- Abir Ben Khaled, Distributed real time simulation of numerical models: application to powertrain, Grenoble INP, Jan. 2011 - Dec. 2013, co-advised by D. Simon and M. Ben Gaid (Institut Française de Pétrole Energies Nouvelles).
- Gabriel Rodrigues de Campos, Systèmes coopérants à travers un réseau de communication sans fil, Grenoble INP, Oct. 2009 - Sep. 2012, co-advised by A. Seuret and C. Canudas de Wit.
- Dominik Pisarski, Collaborative Ramp Metering Control: Application to Grenoble South Ring, UJF, Jun. 2011 - May. 2014, advised by C. Canudas de Wit.
- Luc Malrait, Experience with ConSer: a performance analysis based on dynamical systems on chip, Grenoble INP, Oct. 2007 - Dec. 2011, co-advised by N. Marchand and S. Bouchenak (SARDES).
- Nicolas Cardoso de Castro, Energy-aware communication and control co-design for networked control systems, Grenoble INP, Mar. 2009 - Feb. 2012, advised by C. Canudas de Wit and since Sept. 2010 co-advised by F. Garin.
- Luis Leon Ojeda, Macroscopic modelling, travel demand and flow prediction for Intelligent Transportation Systems, Grenoble INP, Avr. 2011 - Mar. 2014, co-advised by C. Canudas de Wit and A. Kibangou.
- Ruggero Fabbiano, Collaborative source seeking control, Grenoble INP, Dec. 2011 - Nov. 2014, co-advised by C. Canudas de Wit and F. Garin.
- Valentina Ciarla, Commande d'un système de puissance électrique pour personne âgée et/ou handicapée, Grenoble INP, Dec. 2010 - Nov. 2013, co-advised by C. Canudas de Wit, Franck Quaine (UJF) and Violaine Cahouet (UJF).
- Wenjie Lu, Variable Speed Limit Control for Highways, Grenoble INP, Sep. 2011 - Aug. 2014, co-advised by C. Canudas de Wit and A. Ferrara (University of Pavia).
- Riccardo Ceccarelli, The development of a model-based observer for the identification of several types of engine failures, Grenoble INP, Oct. 2007 - Dec. 2011, co-advised by C. Canudas de Wit and P. Moulin (IFP Energies Nouvelles).

PhD defended:

- Sylvain Durand, Reduction of the energy consumption in embedded electronic devices with low control computational cost [12], Grenoble INP, 17/01/2011, co-advised by N. Marchand and D. Simon.
- Lara Briñón-Arranz, Commande coopérative d'une flottille de véhicules sous-marins avec contraints de communication [11], Grenoble INP, 18/11/2011, co-advised by C. Canudas de Wit and A. Seuret.

- Emilie Roche, Commande à échantillonnage variable pour les systèmes LPV : application à un sous-marin autonome [13], Grenoble INP, 18/10/2011, co-advised by O. Sename and D. Simon.

Master students:

- Wenjie Lu, Balancing control for Discrete PDEs in conservation systems, GIPSA-LAB, Apr.-Jun. 2011, advised by C. Canudas de Wit.
- Samir Hachour, Fault detection and isolation in a solar power-plant, ENSISA/GIPSA-LAB, Feb.-Aug. 2011, co-advised by A. Kibangou and F. Garin.
- Eric Davit, Quadrotor control, GIPSA-LAB, Feb.-Jun. 2011, co-advised by A. Seuret and L. Briñón Arranz.
- Yijing Chen, Traffic control, GIPSA-LAB, Apr.-Jun. 2011, advised by C. Canudas de Wit.
- Nassim Mokrani, Asynchronous control for complex systems, GIPSA-LAB, Feb.-Jun. 2011,co- advised by A. Seuret and D. Simon.

Bachelor students:

- Guillaume Gay, Traffic control, GIPSA-LAB, Feb.-May. 2011, advised by C. Canudas de Wit.
- Pierre Gault, Traffic control, GIPSA-LAB, Feb.-May. 2011, avised by C. Canudas de Wit.
- Kevin Planchet, ORCCAD developement, ENSIMAG, Jun.-Sept. 2011, advised by D. Simon.
- Matthew Fitch, Energy-aware sensors, INRIA/Cambridge University, Jul. 2011, co-advised by N. Cardoso de Castro and F. Garin.

# 10. Bibliography

## Major publications by the team in recent years

[1] C. AUBRUN, D. SIMON, Y.-Q. SONG. *Co-design Approaches for Dependable Networked Control Systems*, ISTE Wiley, 2010, http://hal.inria.fr/inria-00443847/en/.

[2] C. CANUDAS DE WIT, F. GOMEZ-ESTERN, F. RUBIO. *Delta-Modulation Coding Redesign for Feedback-Controlled Systems*, in "IEEE Transactions on Industrial Electronics", 2009, vol. 56, n$^{o}$ 7, p. 1-20, http://hal.archives-ouvertes.fr/hal-00394981/en/.

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[5] P. DOLCINI, C. CANUDAS DE WIT, H. BECHART. *Dry Clutch Control for Automotive Applications*, Advances in Industrial Control, Springer, Oct 2010, http://hal.inria.fr/hal-00536612/en.

[6] A. Y. KIBANGOU, G. FAVIER. *Tensor analysis for model structure determination and parameter estimation of block-oriented nonlinear systems*, in "IEEE Journal of Selected Topics in Signal Processing", 2010, vol. Special issue on Model Order Selection in Signal Processing Systems, vol. 4, n^o 3, p. 514-525, http://hal.inria.fr/hal-00417815/en.

[7] Y.-J. PAN, C. CANUDAS DE WIT, O. SENAME. *A new predictive approach for bilateral teleoperation with applications to drive-by-wire systems*, in "IEEE Transaction on Robotics", December 2006, vol. Vol. 22, n^o No. 6, p. 1146-1162.

[8] D. ROBERT, O. SENAME, D. SIMON. *An $H_\infty$ LPV design for sampling varying controllers : experimentation with a T inverted pendulum*, in "IEEE Transactions on Control Systems Technology", 2010, vol. 18, n^o 3, p. 741-749, http://hal.archives-ouvertes.fr/hal-00448496/en/.

[9] A. SEURET, C. PRIEUR. *Event-based sampling algorithms based on a Lyapunov function*, in "50th IEEE Conference on Decision and Control and European Control Conference (IEEE CDC-ECC 2011)", Orlando, Floride, United States, December 2011, 6, http://hal.inria.fr/hal-00610542/en.

[10] A. SEURET. *A novel stability analysis of linear systems under asynchronous samplings*, in "Automatica", October 2011, http://hal.inria.fr/hal-00610561/en.

# Publications of the year

## Doctoral Dissertations and Habilitation Theses

[11] L. BRIÑON ARRANZ. *Commande coopérative d'une flottille de véhicules sous-marins avec contraintes de communication*, Institut National Polytechnique de Grenoble, Nov 2011.

[12] S. DURAND. *Reduction of the energy consumption in embedded electronic devices with low control computational cost*, Institut National Polytechnique de Grenoble, Jan 2011.

[13] E. ROCHE. *Commande à échantillonnage variable pour les systèmes LPV : application à un sous-marin autonome*, Institut National Polytechnique de Grenoble, Oct 2011.

## Articles in International Peer-Reviewed Journal

[14] C. ALBEA, F. GORDILLO ÁLVAREZ, C. CANUDAS DE WIT. *High Performance Control Design for Dynamic Voltage Scaling Devices*, in "Circuits and Systems I: Regular Papers, IEEE Transactions on", December 2011, vol. 58, n^o 12, p. 2919 - 2930 [*DOI :* 10.1109/TCSI.2011.2158707], http://hal.inria.fr/hal-00642260/en.

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[21] A. SEURET. *A novel stability analysis of linear systems under asynchronous samplings*, in "Automatica", October 2011, http://hal.inria.fr/hal-00610561/en.

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[22] R. CARLI, G. COMO, P. FRASCA, F. GARIN. *Distributed averaging on digital noisy networks*, in "IEEE Information Theory and Applications Workshop (ITA Workshop)", San Diego (California), United States, 2011, p. 1-9 [*DOI :* 10.1109/ITA.2011.5743573], http://hal.inria.fr/inria-00581398/en.

## International Conferences with Proceedings

[23] A. S. ABOUBEKR, D. GWENAËL, R. PISSARD-GIBOLLET, É. RUTTEN, D. SIMON. *Automatic generation of discrete handlers of real-time continuous control tasks*, in "IFAC World Congress 2011", Milano, Italy, August 2011, http://hal.inria.fr/hal-00640406/en.

[24] P. J. ANDRIANIAINA, A. SEURET, D. SIMON. *Robust control under weakened real-time constraints*, in "CDC/ECC 2011", Orlando, United States, December 2011, http://hal.inria.fr/hal-00640403/en.

[25] A. BEN KHALED, M. BEN GAÏD, D. SIMON. *Towards a Weakly-Hard Approach for Real-Time Simulation*, in "5th Junior Researcher Workshop on Real-Time Computing", Nantes, France, September 2011, http://hal.inria.fr/hal-00640521/en.

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[27] L. BRIÑON ARRANZ, A. SEURET, C. CANUDAS DE WIT. *Collaborative Estimation of Gradient Direction by a Formation of AUVs under Communication Constraints*, in "50th IEEE Conference on Decision and Control and European Control Conference (IEEE CDC-ECC 2011)", Orlando, Floride, United States, December 2011, 6, http://hal.inria.fr/hal-00619482/en.

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[35] A. FARHADI, C. CANUDAS DE WIT. *An Integration Framework For Control/Communication/Computation (3C) Co-design With Application In Fleet Control Of AUVs*, in "50th IEEE Conference on Decision and Control and European Control Conference", Orlando, United States, December 2011, http://hal.inria.fr/hal-00642028/en.

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[37] A. Y. KIBANGOU, L. F. DE ALMEIDA, L. F. ANDRÉ. *Distributed Khatri-Rao Space-Time coding and decoding for cooperative networks*, in "19th European Signal Processing Conference (EUSIPCO 2011)", Barcelonne, Spain, August 2011, p. 809-813, http://hal.inria.fr/hal-00598662/en.

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[39] I. - C. MORARESCU, C. CANUDAS DE WIT. *Highway traffic model-based density estimation*, in "2011 American Control Conference - ACC 2011", San Francisco, Californie, United States, July 2011, http://hal.inria.fr/hal-00581801/en.

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