

RESEARCH CENTRE

**Grenoble - Rhône-Alpes**

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2021

ACTIVITY REPORT

Project-Team

DANCE

## **Dynamics and Control of Networks**

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

### **DOMAIN**

**Applied Mathematics, Computation and  
Simulation**

### **THEME**

**Optimization and control of dynamic  
systems**

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## **Project-Team DANCE**

*Creation of the Project-Team: 2021 February 01*

### **Keywords**

#### **Computer sciences and digital sciences**

- A1.2.6. – Sensor networks
- A1.2.7. – Cyber-physical systems
- A1.2.9. – Social Networks
- A1.5. – Complex systems
- A6.1.1. – Continuous Modeling (PDE, ODE)
- A6.1.3. – Discrete Modeling (multi-agent, people centered)
- A6.4. – Automatic control
- A8.8. – Network science

#### **Other research topics and application domains**

- B2.3. – Epidemiology
- B6.3.4. – Social Networks
- B7. – Transport and logistics
- B8.2. – Connected city

## 1 Team members, visitors, external collaborators

### Research Scientists

- Paolo Frasca [Team leader, CNRS, Researcher, from Feb 2021]
- Carlos Canudas de Wit [CNRS, Senior Researcher, from Feb 2021]
- Maria-Laura Delle Monache [Inria, Researcher, from Feb 2021 until Jun 2021]
- Federica Garin [Inria, Researcher, from Feb 2021]

### Faculty Members

- Hassen Fourati [Univ Grenoble Alpes, Associate Professor, from Feb 2021]
- Alain Kibangou [Univ Grenoble Alpes, Associate Professor, from Feb 2021]

### Post-Doctoral Fellows

- Martin Rodriguez [CNRS, from May 2021]
- Fadoua Taia-Alaoui [Univ Grenoble Alpes, from Feb 2021 until Mar 2021]

### PhD Students

- Maria Castaldo [CNRS, from Feb 2021]
- Muhammad Umar B Niazi [Inria, from Feb 2021 until Jun 2021]
- Denis Nikitin [CNRS, from Feb 2021 until Aug 2021]
- Bassel Othman [IFPEN, from Feb 2021 until Sep 2021]
- Ujjwal Pratap [CNRS, from Feb 2021]
- Martin Rodriguez [CNRS, from Feb 2021 until Apr 2021]
- Tommaso Toso [CNRS, from Oct 2021]
- Liudmila Tumash [CNRS, from Feb 2021 until Aug 2021]
- Renato Vizuete Haro [Univ Paris-Saclay, from Feb 2021]
- Makia Zmitri [CNRS, from Feb 2021 until Sep 2021]

### Technical Staff

- Vadim Bertrand [CNRS, Engineer, from Feb 2021 until Aug 2021]
- Leo Senique [Inria, Engineer, from Feb 2021]

### Interns and Apprentices

- Xiaochen Li [Inria, from Feb 2021 until Jul 2021]

### Administrative Assistant

- Myriam Etienne [Inria, from Feb 2021]

## 2 Overall objectives

DANCE is a joint research team of Inria Grenoble – Rhône-Alpes and **GIPSA-lab**, established in February 2021 as the evolution of former team **NeCS**. The team is bilocated at the Inria center in Montbonnot and at Gipsa-Lab on Saint-Martin-d’Hères campus, both locations being in the Grenoble area.

The team’s mission is to advance the field of Automatic Control to meet the challenges of today’s hyper-connected society. We perform both fundamental research about control systems theory and network science and applied research in relevant domains such as mobility, transportation, social networks, and epidemics.

Both researchers and general public have become aware that our society and our lives depend on **complex dynamical systems** that can be understood as **networks**. Examples are plentiful and we shall only remind a few: transportation networks allow ourselves to travel, commute, and transport goods; power networks provide our homes and factories with energy; supply chains are the backbone of manufacturing; social networks support our professional and personal relationships; networks of neurons constitute our brains; and ecological networks such as foodwebs sustain our survival.

In stark contrast with this reality and its popular recognition, the mathematical and conceptual tools available to scientists and engineers to understand and manage these systems are lagging behind. We believe that these *complex network systems are first and foremost dynamical systems* and therefore amenable to an Automatic Control approach, since Automatic Control, as a field, is devoted to study dynamics and the ways to monitor and to regulate them. However, the century-old theory of Automatic Control has been developed to study other kinds of mechanical or electrical systems that lack a network structure: inspecting a 1999 landmark book like [62] shows that control theorists did not yet consider networks to be a topic of study as late as 20 years ago. Despite substantial efforts by the research community during the last 15 years, the theory of systems and control has not yet been able to integrate itself with the big advances that have been made in network science. The ambition of this team is to contribute to closing this gap.

The research of the DANCE team encompasses both methodological work and applications in close interdependence since methodological questions are motivated by selected application areas. The dominant one is the broad area of **mobility**. By this term we encompass questions about vehicular and multi-modal transportation, navigation methods for pedestrians in urban and cluttered/noisy environments, and Connected Autonomous Vehicles, namely their cooperative behavior and their effect on the overall transportation system. The team maintains and develops experimental platforms on mobility, including the **GTL** (Grenoble Traffic Lab) [66], **GTL-Ville**, and **GTL-Covid**. A growing application area concerns **social systems**, mainly in relation with the dynamics that take place in online social media: on this topic we collaborate at the national and international levels with researchers from engineering, computer science and social sciences. The mathematical methods developed by the team may also find potential application in other areas that team members are currently exploring: brain networks (by a control perspective on Deep Brain Stimulation), smart buildings (seen as a large-scale systems), networks of oscillators, and biological networks (biochemical and epidemical networks).

From our application scenarios, it appears that the networks that we are interested in share several important features:

- they are inherently dynamical and their evolution can be influenced from the outside;
- their structure (that is, the topology of their interconnections) shapes their global behavior;
- their structure and their composition evolve together with the evolution of their components;
- they are large and therefore require tools that scale well with size;
- their dynamics, structure, and state are known with possibly large uncertainties (even though they may generate big data streams).

Our approach is a **control systems approach**, that begins by identifying suitable state variables, input variables and output variables. To cope with the specific features of complex network systems, we develop

new system-theoretic tools for modeling, estimation, and control. Depending on the application and on the modeling methodology, the mathematical models will be differential (or difference) equations on graphs or continuous models such as partial differential equations. In the applications, estimation and control take advantage of the structure of the systems and of their specific, physical, features.

### 3 Research program

In presenting our research, we shall distinguish five research *Axes*. The first two axes present our theoretical work that develops a broad set of tools for modeling, identification and control of network dynamics. Focusing on the nexus between networks and control systems implies that our methods will blend ideas from network science and control science. The first axis regards methods that define network dynamics by the graph that naturally describes their physical or informational structure; the second axis goes beyond this graph-theoretic representation by using approximations or aggregations to deliver methods that are suitable to large networks. The remaining three Axes present methods that are tailored to our main applications in transportation, in social networks, and in epidemics.

#### Research Axis 1: Exact Automatic Control methods for networks

Most methods from Automatic Control do not apply well to networks, simply because they were designed for systems that do not have a network structure. Once the presence of network structure is recognized, it has to be accounted for in analysis and design. Firstly, a network structure implies *obstructions to the flow of information* between different parts of the system. A key instrument to take them into account is the deployment of graph-theoretical methods, as we will exemplify below. Secondly but not less importantly, a network structure implies the opportunity (or sometimes the need) to *scale* the network up in size, growing larger and larger networks by the addition of nodes and edges. Sometimes, classical control methods scale poorly in terms of complexity or performance, and therefore need overhaul. This research axis therefore pertains to the development of system-theoretic methods that are based on graph theoretical representations of the system and whose complexity and performance scale well with the size of the network, so that networks with tens or hundreds of nodes can be studied.

#### Research Axis 2: Approximate methods for large-scale networks

Axis 1 was devoted to the control-theoretic analysis of networks by Graph Theory tools, under the assumption that a complete knowledge of the network is available. These methods are suitable for systems with a relatively small number of nodes (tens or hundreds), like formations of moving robots or sensor networks, but become ineffective for larger networks. Complete knowledge of the network is typically not available, because of the presence of noise, errors in data, links changing in time. Additionally, even if in some cases it is possible to obtain a good approximation of the network structure, the applicability of estimation and control methods is reduced by the limitation of computational resources. In order to address these limitation, this research axis (Axis 2) develops system-theoretic methods that abstract from the detailed network state, by performing operations of aggregation or approximation. These tools are meant to be applied to networks with thousands of nodes.

The remaining three axes develop methods that are directly motivated by the applications: we therefore describe them in the next section.

## 4 Application domains

### Smart Transportation Systems

Smart transportation is the main domain of application for the team. The research topics include cooperative control of Connected and Autonomous Vehicles, pedestrian navigation, vehicular traffic in urban road networks, and multi-modal transportation. The experimental platforms Grenoble Traffic Lab (GTL) and GTL-Ville continuously collect real-time data about traffic in Grenoble. Other data collection campaigns, such as TMD-CAPTIMOVE, have produced datasets about multi-modal transportation.

Transportation research is currently at a crucial stage: we are facing the emergence of new technologies and systems such as vehicle connectivity, automation, shared-mobility, multimodal navigation and advanced sensing which are rapidly changing mobility and accessibility. This in turn will fundamentally transform how transportation planning and operations should be conducted to enable smart and connected communities. On one hand, this process presents us with a great opportunity to build safer, more efficient, reliable, accessible, and sustainable transportation systems. On the other hand, the uncertainties regarding how such disruptive technologies will evolve pose a number of fundamental challenges. These challenges include: (a) understanding the impacts of connected and automated vehicles on the traffic flow; (b) shifts in travel demand induced by new paradigms in mobility, such as shared mobility; (c) the computational challenges of real-time control strategies for large-scale networks, enabled by emergent technologies; (d) transitioning to predictive and proactive traffic management and control, thus substantially expanding the horizons of transportation network management; (e) the need for identifying different modes of transport used by a certain population. The need to effectively address these challenges provides the opportunity for fundamental advances in transportation and navigation and will be the object of this research axis.

### Cyber-Social Systems

Online social networks, such as online blogging platforms and social media, are chief examples of complex systems where social and technological components interact. We can refer to such systems as *Cyber-social networks*: social components are human individuals whose collective behavior produces the overall behavior of the system, whereas technological (or cyber) components are devices or platforms endowed with sensing, computation, and communication capabilities. In these contexts, the interactions between the individuals are mediated and determined by the ubiquitous presence of digital technology. Online social services routinely record behaviors and interactions and exploit this information to constantly optimize themselves for the users, by the ubiquitous presence of recommendation systems. These large data streams can also enhance our understanding of social dynamics. Beyond the analysis power, these tools offer new opportunities to influence the behaviors of the individuals. This influence can be obtained in various ways, including advertising, diffusing sensitive information, or altering the way individuals interact. These evidences open the way to identify ways to “actuate” (in engineering jargon) social systems. Understanding these dynamics in a control systems perspective is thus not only a scientific challenge, but also an urgent need for the society.

### Epidemics

The current COVID-19 pandemics has proved how important is the understanding of network dynamics to mitigate and contain epidemics. The group has taken up this challenge and produced multiple contributions that leverage our expertise about control of networks, social networks, online media, and human mobility. Indeed, our research on network dynamics has long time considered networked epidemic models (such as SIS or SIR) as “academic” examples of application. This perspective includes works about epidemics that we published until 2020 [72, 78]. As soon as the Covid-19 pandemics struck, we realized how our expertise could be useful and we initiated several initiatives whose outcomes are summarized in Section 7. These initiatives have leveraged a combination of internal expertise (namely about network dynamics, control, and mobility) and external expertise on mathematical epidemiology (from Institut Pasteur and MAMBA Inria team). A network model of epidemics evolution coupled with human mobility in the Grenoble area can be visualized in the interface GTL-COVID.

## 5 Highlights of the year

Team DANCE has been created in February.

July: Maria Laura Delle Monache has joined the Department of Civil and Environmental Engineering at UC Berkeley.

Supervision: 8 of our students have defended their PhD theses this year.



## 5.1 Awards

T. Moyo was awarded for outstanding academic excellence at the Faculty of Engineering and Built Environment of University of Johannesburg (Dec. 2021).

## 6 New software and platforms

**Participants:** C. Canudas de Wit, M.L. Delle Monache, H. Fourati, P. Frasca, F. Garin, A. Kibangou, L. S enique.

### 6.1 New software

#### 6.1.1 GTL

**Name:** Grenoble Traffic Lab

**Keywords:** Road traffic, Traffic data

**Functional Description:** The Grenoble Traffic Lab (GTL) initiative, led by the NeCS team, is a real-time traffic data Center (platform) that collects traffic road infrastructure information in real-time with minimum latency and fast sampling periods. The main elements of the GTL are: a real-time data-base, a show room, and a calibrated micro-simulator of the Grenoble South Ring. Sensed information comes from a dense wireless sensor network deployed on Grenoble South Ring, providing macroscopic traffic signals such as flows, velocities, densities, and magnetic signatures. This sensor network was set in place in collaboration with Inria spin-off Karrus-ITS, local traffic authorities (DIR-CE, CG38, La Metro), and specialized traffic research centers. In addition to real data, the project also uses simulated data, in order to validate models and to test the ramp-metering, the micro-simulator is a commercial software (developed by TSS AIMSUN  ). More details at <http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php>

**URL:** <http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php>

**Contact:** Carlos Canudas-de-Wit

**Participants:** Alain Kibangou, Andres Alberto Ladino Lopez, Anton Andreev, Carlos Canudas-de-Wit, Dominik Pisarski, Enrico Lovisari, Fabio Morbidi, Federica Garin, Hassen Fourati, Iker Bellicot, Maria Laura Delle Monache, Paolo Frasca, Pascal Bellemain, Pietro Grandinetti, Remi Piotaix, Rohit Singhal, Vadim Bertrand

#### 6.1.2 GTL-Ville

**Name:** Grenoble Traffic Lab - City

**Keyword:** Traffic data

**Functional Description:** The GTL-Ville platform is developed within the framework of the ERC Scale-FreeBack project (<http://scale-freeback.eu/>). Its functions are divided into three axes: 1- Collect traffic data in real time via different sources. We are currently working with three suppliers: TomTom (company) for speed data from Floating Car Data (FCD), La M etro for counting data from existing loops and Karrus (company) to complete the counting data from La M etro via radars deployed since last fall. 2- Estimate traffic indicators with the lowest possible latency using collected data and historical data applied to models developed by PhD students of the ERC project. 3- Visualize raw data and calculated indicators via a web interface (<http://gtlville.inrialpes.fr/>).

**URL:** <http://gtlville.inrialpes.fr>

**Contact:** Carlos Canudas-de-Wit

### 6.1.3 GTL-Covid

**Name:** GTL Covid Simulation

**Keywords:** Road traffic, Epidemiology

**Functional Description:** This project, initiated by the DANCE team with support from Scale-freeBack ERC and the Healthy Mobility Inria project, is a demonstrator of epidemics mitigation through efficient mobility control. First, mobility in the Grenoble urban area is captured through origin destination matrices calibrated thanks to household travel surveys and INSEE data. The mobility is modeled from origins (residences) to destinations (activity-oriented) such as workplaces, schools, hospitals, parks, stores, malls, . . . This mobility model is coupled with a SIR model. Based on this complex model, an optimization engine allows evaluating various scenarios of mobility restrictions.

**URL:** <http://gtlville.inrialpes.fr/covid-19>

**Contact:** Carlos Canudas-de-Wit

## 7 New results

### 7.1 Research Axis 1: Exact Automatic Control Methods for Networks

**Participants:** H. Fourati, P. Frasca, F. Garin, A. Kibangou, R. Vizuete.

#### Open Multi-Agent Systems

Open Multi-Agent Systems, also known as Open Networks or Dynamics Networks, are networks whose nodes can exit or enter the network at any time, as opposed to closed networks whose node set is fixed. In practice, this is a relevant question because large networks and populations often evolve with time. Mathematically, the evolution of the node set makes the utilisation of control-theoretic notions, such as stability, delicate. Results have been obtained by two approaches. First, we have studied the stability of consensus in an open system under the assumption of having a finite “universe” set of possible nodes, from which the actual nodes of the network are chosen [26]. Second, we have studied the stability of contractive dynamics in the presence of joining/leaving nodes, essentially by understanding the process of node arrival/departure as a disturbance [10]. Additionally, we have studied multi-agent optimization problems in the presence of replacements of the agents: some preliminary convergence results have been presented in [33]. Future work on OMAS will resort to the approximation methods that are described in Axis 2.

#### Cyber-Physical Systems: a control-theoretic approach to privacy and security

Cyber-physical systems are composed of many simple components (agents) with interconnections giving rise to a global complex behaviour. One line of research on security of cyber-physical systems models an attack as an unknown input being maliciously injected in the system. We study linear network systems, and we aim at characterizing input and state observability (ISO), namely the conditions under which both the whole network state and the unknown input can be reconstructed from some measured local states. We complement the classical algebraic characterizations with novel structural results, which depend only on the graph of interactions (equivalently, on the zero pattern of the system matrices). More precisely, we consider a structured system, namely a family of linear systems, where the graph of interactions is fixed while the intensities of interactions (edge weights) are free parameters. We obtain two kinds of results: structural results, true for almost all interaction weights, and strongly structural results, true for all non-zero interaction weights. Our recent results deal with strongly structural ISO for time-invariant systems [11]. We provide first a graphical characterization for s-structural unconstrained ISO, where the input reconstruction might happen with some unspecified delay. Then, we provide sufficient conditions and necessary conditions for s-structural ISO, where we ensure that the input at

time  $(k-1)$  can be reconstructed at time  $k$ . The conditions presented are in terms of existence of suitable uniquely restricted matchings in bipartite graphs associated with the structured system. In order to test these conditions, we present polynomial-time algorithms. We also discuss an equivalent reformulation of the main conditions in terms of coloring algorithms as in the literature of zero forcing sets.

## 7.2 Research Axis 2: Approximate methods for large-scale networks

**Participants:** C. Canudas de Wit, M.L. Delle Monache, H. Fourati, P. Frasca, F. Garin, A. Kibangu, D. Nikitin, L. Tumash, V. Bertrand, M.U.B. Niazi, U. Pratap.

### Node aggregation and scale-free methods

The task of controlling large-scale networks is very difficult in the first place because of its large dimensionality, making the computation of traditional control algorithms too expensive. In systems of large dimensions, the number of sensors is often much lower than the number of states, which makes it hard to identify the mathematical model of the system and to estimate its state. Similar issues arise regarding the number of actuators. Another difficulty is that the energy needed to control all nodes of the network can grow exponentially with the number of nodes, at least for some network structures [74]. Therefore, in some cases, it can be preferable to *control and estimate some aggregated measure* of the entire network rather than all individual states, since the energy required to control aggregated quantities instead of all network states is much less. Examples of aggregate quantities would be, for instance, the average state of the whole network and its variance, or the average values in different regions of the network.

Therefore, the scale-free approach that is developed in the ERC Scale-FreeBack project is based on the aggregation of the variables that belong to neighboring nodes. The aggregation is done in such a way to construct a scale-free network, where the goal is to control the averaged state and the variance of the hubs, corresponding to regions or groups of nodes, and the control is applied to the boundaries of the hubs. In scale-free dynamic network modelling & analysis, the purpose is to reduce the system network complexity by finding the appropriate level of scale aggregation, while imposing the control and observation model properties required. For instance, the problem of robust state reconstruction is considered in [21] and the state reconstruction problem is applied to vehicular traffic density in urban transportation networks [22]. The ultimate goal has consisted in developing novel control methods for scale-free network systems [20]. The team has applied these novel tools to traffic networks, namely in the GTL Ville experimental platform.

### The continuation method

When considering limit models for large networks, we naturally fall into continuous limits. These limits can take different forms. One way to define continuous limits is to regard, instead of the agent states, their *distribution*. The evolution of the distribution would then be naturally described by a partial differential (PDE) or integro-differential equation. A good approximation implies that control actions can be designed on the continuous system and have guaranteed performance on the original (graph-based) one. By the thesis work of D. Nikitin and a series of papers, we have reached a twofold objective: (1) we have developed a sound and complete theoretical framework for the PDE approximation of large networked ODE systems [19]; and (2) we have applied this framework to multiple applications including swarms of autonomous robots [19], traffic networks [59], laser arrays [36], spin-torque oscillators [55].

### Graphons

Another promising way to define continuous limits is by the concept of graph function, or *graphon*, which is the limit object of a sequence of dense networks [71, 63, 64]. Conversely, finite graphs can be generated by sampling from the continuous graphon: in this case, the properties of the finite networks can be inferred from the properties of the graphon. Recent works related to the application of graphons include the study of dynamics over networks [69, 70], centrality measures [61], link prediction [79], large

population games [73, 65]. Inspired by very recent results on centrality measures [61], we have been able to use graphons to define performance *metrics* that quantify system-theoretic properties like stability, controllability, or sensitivity to noise [78]. These metrics can be computed from the graphon at low computational cost and approximate well the system-theoretic properties of the corresponding dynamics on graphs of large-but-finite size [27].

### 7.3 Research Axis 3: Mobility systems and transportation networks

**Participants:** C. Canudas de Wit, M.L. Delle Monache, H. Fourati, P. Frasca, F. Garin, A. Kibangou, L. Tumash, V. Bertrand, U. Pratap, M. Rodriguez Vega, T. Moyo, B. Othman, F. Taia Alaoui.

#### Network-level traffic estimation, prediction and control

Methods for traffic estimation, prediction and control have been widely studied for highway traffic, but need significant advances to extend to urban traffic. Indeed, urban traffic is by nature a network problem, with issues about modeling intersections, and about dealing with the increased complexity. Our contributions have covered both estimation and prediction problems and control design.

Regarding traffic state **estimation** in urban networks, our contributions have dealt with three main sub-problems. First, the optimal sensor location problem was considered. In [39], the location of turning ratio sensors is considered for the dynamic case, under a limited number of available sensors. The second problem considers the estimation of flow and density using heterogeneous sources of information, such as fixed sensors and aggregated vehicle velocities from Floating Car Data (FCD). In [39] and [38], we used FCD speed information directly to better model urban intersections. For the third problem, we consider the estimation of the aggregated density of an urban network. To solve this problem, we propose a method to calculate a virtual representation of the same underlying physical network where each road is divided into a number of cells, such that the estimator for the virtual system converges. We show that the difference between the real and virtual averages is small. Contributions for this problem were published in [38]. These contributions were tested using real data collected in the city of Grenoble via the Grenoble Traffic Lab for urban networks (GTL-Ville).

Regarding **control design**, we have studied control of traffic networks where the actuators can be either traffic lights schedule or variable speed limits. Most recently, we switched our focus from classical traffic performance objectives to suitably-defined performance indexes, so as to study and minimise the fuel consumption and hence the ecological impact of traffic [37, 45]. To estimate the fuel consumption, a macroscopic network traffic model is associated with an artificial neural network calibrated using a microscopic physical energy model and data provided by a microscopic traffic simulator. We find that speed limits directly impact energy consumption and pollutant emissions, as they affect the accelerations and average speeds through the network. We design controllers with variable speed limits and with signalized access control, for improved environmental sustainability and traffic performance both in a synthetic urban area and in the peri-urban area at its boundaries. Controllers are designed with non-linear model predictive control, in which the traffic evolution and the fuel consumption are predicted with macroscopic models, and then evaluated using the microscopic traffic simulator SUMO and a physical fuel consumption and NOx emission model. The results reveal that in transient phases between different levels of congestion, the variable speed-limit controller is faster to decongest the network, in an energy-efficient way, resulting in an improvement of the environmental sustainability and the traffic performance both in the controlled network, and at its boundary roads.

#### 2D traffic models

Macroscopic traffic models use classical fluid dynamics equations to describe car flow on a stretch of road where vehicles are treated as infinitesimal particles and we look at the evolution of their density. The basic evolution equation, which corresponds to mass conservation, expresses the conservation of the number of vehicles. Models that tried to extend this idea to traffic flow on road networks have not been successful in representing correctly traffic dynamics on networks. In fact, state-of-the-art traffic

assignment models integrate traffic dynamics based on first-order nonlinear partial differential equation (PDE) models such as the Lighthill-Whitham-Richards (LWR) model, but they have some limitations in terms of their scalability and computation time due to the complexity of the underlying assignment problem. In our perspective, it is fundamental for traffic control, understanding the network effects and design network models that capture how the various traffic streams interact and evolve throughout the network. We have addressed the problem of describing correctly traffic flow dynamics on networks by using new concepts as 2D models and micro-macro models on networks, in relation with the research undertaken in Axis 2. The second generation came out this year through the thesis work of L. Tumash [51], as well as novel control techniques that involve boundary control and traffic demand [25].

### **Heterogeneity and autonomy in traffic**

After 70 years of research, traffic flows of homogeneous vehicles are fairly well understood. More elusive is the understanding of heterogeneous traffic flows. As of today, a novel and peculiar sort of heterogeneity is appearing in traffic: the presence of automated (possibly autonomous) and connected vehicles (CAVs). Their appearance has motivated us to assess their impact on traffic and explore their potential as means for estimation and for control. Indeed until recently, traffic control infrastructures, such as ramp metering systems and variable speed limits, have been considered to be the essential tools for all traffic estimation and control goals, for instance mitigation of fluctuations in traffic flow. Today, instead, the advances in automation have brought the idea of exploiting CAVs for traffic control purposes.

In 2018, the first experimental result has finally been showed in [75]: using the same ring setup of [76], one of the HVs was replaced with an AV, so as to obtain a mixed traffic scenario with a single AV. Such a ring setup approximates a scenario in which AVs are sparsely and periodically introduced in the traffic. Starting from this practical evidence of the possibility of controlling traffic flow via a limited number of autonomous vehicles, our team has developed the rigorous analysis of these experiments. Our approach has been to assess the effects, and potential improvements, of autonomous vehicles in terms of system-theoretic properties of the collective vehicle dynamics, such as of *stability and string stability* [13, 12]. To this goal we have exploited tools that pertain to Axis 1, where the vehicles constitute the nodes of a network of interactions.

Further results have been obtained about the coordination of CAVs in challenging situations of merging maneuvers [14] and of unreliable communication [6].

### **Multimodal mobility & pedestrian navigation**

Mobility is currently evolving in urban scenarios and multimodality today is the key to more efficient transportation. In order to analyze the ecological impact of the various transportation modes, it is important to be able to detect the mode used by the commuter and the rule used to switch from one mode to another. The ultimate goal is to suggest smarter itineraries to commuters. To this purpose, detection and classification of activities in human mobility from one's principal residence to one's destination (for example, place of work, place of entertainment, etc.) is an important study to carry out. We aim to identify, with high precision, the nature of the transportation modes used during the day (walking, cycling, public transportation, car, etc.) as well as transitions from one mode to another. To reach this goal, our studies involve inertial and attitude modules, embedded in most inertial units, connected watches and smartphones. These technological tools constitute truly innovative and promising instrumentation for non-invasive automatic information capture. In [41] we have devised machine learning approaches for transportation mode detection (bus, tramway, walking, bike, kick scooter), by using features extracted from IMUs (Inertial Magnetic Units). The location of sensors on the body is crucial in order to get accurate results.

Another relevant issue in pedestrian navigation is estimating the velocity of a moving body. In [29] we propose an innovative method that only uses raw data from a triad of low-cost inertial sensors, i.e. accelerometer and gyroscope, as well as a determined arrangement of magnetometer array. The proposed approach combines a magnetic field gradient-based Extended Kalman Filter (EKF), with a Bidirectional Long Short-Term Memory (BiLSTM) network. This is to better estimate the velocity, especially when the magnetic field disturbances are low, which causes other magnetic field-based methods to be inaccurate. The proposed method also makes it possible to well update the velocity regardless of sensor location,

without any heavy computation or complex tuning, as the case for the Zero-Velocity Update Technique (ZUPT). The performance of the proposed approach is demonstrated through real experiments data using a Magneto-Inertial Tachymeter (MIT). The obtained results show the efficiency of the velocity and position estimation, for different sensor placements and trajectory scenarios.

An independent line of research in multimodality deals with network optimization for multimodal transportation. Considering the case of the city of Johannesburg, South Africa, we have devised new techniques for network design for integrating non-motorized transportation mode to a bus network. For this purpose a societal cost is included in the optimization problem [16].

## 7.4 Research Axis 4: Social dynamics and Cyber-social networks

**Participants:** P. Frasca, M. Castaldo, N. Bouarour.

### Opinion dynamics and social influence

Models of social influence are much studied in network science to understand the dynamics of opinions and beliefs. The team activity in this field has been focused on the following issue [68]. Social influence, through phenomena of imitation and peer pressure, tends to favour the agreement of opinions and beliefs: nevertheless, disagreement persists in social groups. How can we explain the persistence of disagreement? Our research has rigorously studied multiple mathematical models that aim to understand the persistence of disagreement. The most recent results regard the effects of limited confidence between peers [44], which can explain the formation of opinion groups. Studying these dynamics has required to solve delicate mathematical questions related to switching, nonsmooth and hybrid dynamical systems [67].

### Attention dynamics in social media

According to some popular narrative, social media are plagued by issues like the viral diffusion of *fake news* and the formation of *filter bubbles*, that is situations in which an Internet user encounters only information and opinions that conform to and reinforce his/her own beliefs. Our research makes the hypothesis that these phenomena are a natural byproduct of the very nature of online social networks, which make interactions highly dynamical and introduce unprecedented effects of *feedback* and scale through the action of algorithms that measure, personalize, and monetize an individual's online experience [77]. Our research more precisely concentrates on what we can call "trending bubbles": digital media and their algorithms concentrate the public debate, drawing a disproportionate amount of attention on a few items and then away from them in a very short time. These effects derive from the tendency to emphasize novelty and timeliness in terms of identifying unprecedented surges of activity. Concretely, this line of research aims at identifying the concentration and scattering of media attention through a parsimonious mathematical model that captures the time evolution of collective behaviors. We have already developed a mathematical model for the attention dynamics [7] and we are currently testing the predictions of the model on data sets collected with our partners at CIS, Paris, to record the fruition of contents on selected YouTube channels and on Twitter.

### Feedback in recommendation systems

In online platforms, recommender systems are responsible for directing users to relevant contents. In order to enhance the users engagement, recommender systems adapt their output to the reactions of the users, who are in turn affected by the recommended contents. This reciprocal influence creates a feedback loop that is the focus of our work. Our main result so far has been a tractable analytical model of a user that interacts with an online news aggregator [24]. Creating this model has required three delicate steps:

1. defining the model of the user (who assimilates the received information with a confirmation bias);



2. defining the model of the recommender (that proposes items with the goal of maximizing the number of user's clicks);
3. specifying their interconnection, that is, the information that they exchange.

This model is able to analytically underline the feedback loop between the evolution of the users opinion and the personalised recommendation of contents, and yields qualitative predictions that support the concerns about potential long-term effects on the consumption of contents by users. Ongoing work is addressing the experimental validation of these results.

## 7.5 Research Axis 5: Epidemics modeling, estimation and control

**Participants:** C. Canudas de Wit, P. Frasca, F. Garin, A. Kibangou, M. Castaldo, M.U.B. Niazi, D. Nikitin, U. Pratap, L. S enique, L. Tumash.

### Testing strategies

Testing is a crucial control mechanism in the beginning phase of an epidemic when the vaccines are not yet available. It enables the public health authority to detect and isolate the infected cases from the population, thereby limiting the disease transmission to susceptible people. However, despite the significance of testing in epidemic control, the recent literature on the subject lacks a control-theoretic perspective. In our papers [35, 17], an epidemic model is proposed that incorporates the testing rate as a control input and differentiates the undetected infected from the detected infected cases, who are assumed to be removed from the disease spreading process in the population. After estimating the model on the data corresponding to the beginning phase of COVID-19 in France, two testing policies are proposed: the so-called best-effort strategy for testing (BEST) and constant optimal strategy for testing (COST). The BEST policy is a suppression strategy that provides a minimum testing rate that stops the growth of the epidemic when implemented. The COST policy, on the other hand, is a mitigation strategy that provides an optimal value of testing rate minimizing the peak value of the infected population when the total stockpile of tests is limited. Both testing policies are evaluated by their impact on the number of active intensive care unit (ICU) cases and the cumulative number of deaths for the COVID-19 case of France.

### Human mobility and epidemics

Reducing human mobility is a very effective non-pharmaceutical intervention to reduce epidemics spread, and lockdowns have been effectively used in various countries in 2020. However, it is clear that mobility reductions have heavy economic and social effects. In our team, we have focused on understanding the interplay of human mobility and epidemics spread at the urban level. Our model [34] is based on an urban mobility model describing daily mobility between homes and destinations such as schools, workplaces, shopping and leisure, coupled with SIR epidemics evolution at each node of the mobility network. Mobility restrictions can be easily described in this model, either by reducing capacity of some destinations, or by reducing opening hours. An optimization problem can then be devised, to maximise economic activity (a suitably weighted average of mobility towards various categories of destinations) under the constraint that epidemics spread remains low enough to avoid saturation of ICU beds in hospitals. The model from [34] has then be extended and implemented to a city-level model that realistically reconstructs mobility in the Grenoble area. As a result, the web interface *GTL-covid* is a platform which can be used to simulate different scenarios of mobility (with or without restrictions of capacity and of opening hours) and visualise their effects on epidemic spread in the Grenoble area.

### Telecommuting strategies

In our paper [15] we develop a simulation study to analyze COVID-19 outbreaks on three real-life contact networks recorded in a workplace, a primary school and a high school in France. Our study provides a fine-grained analysis of the impact of contact-limiting strategies at workplaces, schools and high schools,

including: (1) Rotating strategies, in which workers are evenly split into two shifts that alternate on a daily or weekly basis; and (2) On-Off strategies, where the whole group alternates periods of normal work interactions with complete telecommuting. We model epidemics spread in these different setups using a stochastic discrete-time agent-based transmission model that includes the coronavirus most salient features: super-spreaders, infectious asymptomatic individuals, and pre-symptomatic infectious periods. Our study yields consistent results that can provide guidance for public health decisions related to telecommuting.

### **Societal impact of Covid-19 and lockdowns**

Online platforms register human behaviors and have therefore recorded ample evidence of the behavioral changes that we have endured due to the Covid-19 pandemics and the ensuing lockdowns. The lockdown orders established in multiple countries in response to the Covid-19 pandemic are arguably one of the most widespread and deepest shock experienced by societies in recent years. Studying their impact through the lens of social media offers an unprecedented opportunity to understand the susceptibility and the resilience of human activity patterns to large-scale exogenous shocks. In our work [8] we investigate the changes that this upheaval has caused in online activity in terms of time spent online, themes and emotion shared on the platforms, and rhythms of contents consumption. We also examine the resilience of certain platform characteristics, such as the daily rhythms of emotion expression. We base our analysis on two independent datasets about the French cyberspace: a fine-grained temporal record of almost 100 thousand YouTube videos and a collection of 8 million Tweets between February 17 and April 14, 2020. In both datasets we observe a reshaping of the circadian rhythms with an increase of night activity during the lockdown. The analysis of the videos and tweets published during lockdown shows a general decrease in emotional contents and a shift from themes like work and money to themes like death and safety. However, the daily patterns of emotions remain mostly unchanged, thereby suggesting that emotional cycles are resilient to exogenous shocks. Traffic data collected in the city of Johannesburg during the first lockdown also gives rise to the development of an original modeling approach for essential traffic and its ecological impact [31].

## **8 Bilateral contracts and grants with industry**

**Participants:** H. Fourati.

### **8.1 Bilateral contracts with industry**

**TMI-V** “Tachymètre Magnéto-Inertiel couplé Vision.” Co-PI: H. Fourati (2018-2022).

*Abstract:* The objective of the TMI-V project is the indoor localization without infrastructure, by developing an autonomous, precise, robust solution with no prior knowledge of the environment integrated in equipment worn on the upper body to be used in virtual reality and augmented reality applications. An array of magnetometers and inertial sensors will be used. The project is ongoing, in collaboration with SysNav company.

**FAUCON** “Fusion AUtonome de Capteurs Optroniques-électromagnétiques-inertiels pour la navigation du système de combat aérien future - Partie A: Navigation et Géolocalisation par Vision” in collaboration with the companies “Safran Electronique & Défense” and “Thales AVS”, funded by the “Direction Générale de l’Armement (DGA)”, 2021-2022. Contact: H. Fourati

*Abstract:* During this project, it will be a question of proposing new techniques and new perspectives based on vision data and on inertial measurements of high quality (like that which can be found on high-performance sensors, with a performance class better than 1 Nautical/hour for example). More specifically, it is therefore a question of identifying the candidate architectures of Navigation and Geolocation systems by vision coupled with inertial, making it possible to meet the emerging performance needs of future platforms. The work will include a bibliographic study, as well as a



model (for example Matlab) without depriving themselves of the most audacious and innovative solutions.

## 9 Partnerships and cooperations

**Participants:** C. Canudas de Wit, M.L. Delle Monache, H. Fourati, P. Frasca, A. Kibangou.

### 9.1 International initiatives

#### 9.1.1 Participation in other International Programs

**PercepTrans** P.I.: A. Kibangou- PHC PROTEA, France-South Africa, duration: 2021-2022. Partner: University of Johannesburg.

*Abstract:* PercepTrans aims at merging perception and quantitative measurements to assess quality of service in public transportation by using machine learning techniques. Despite travel restrictions due to COVID-19, data collection has been performed in Johannesburg and Durban in November 2021. Collected data are under analysis. In parallel to this, a model for essential traffic has been derived.

### 9.2 International research visitors

No visits were planned in the current pandemics situation.

### 9.3 European initiatives

#### 9.3.1 FP7 & H2020 projects

**Scale-FreeBack.** ERC Advanced Grant (2016–2022). PI: C. Canudas de Wit.

*Abstract:* The overall aim of Scale-FreeBack is to develop holistic scale-free control methods of controlling complex network systems in the widest sense, and to set the foundations for a new control theory dealing with complex physical networks with an arbitrary size. Scale-FreeBack envisions devising a complete, coherent design approach ensuring the scalability of the whole chain (modelling, observation, and control). It is also expected to find specific breakthrough solutions to the problems involved in managing and monitoring large-scale road traffic networks. Field tests and other realistic simulations to validate the theory will be performed using the equipment available at the Grenoble Traffic Lab center and a microscopic traffic simulator replicating the full complexity of the Grenoble urban network. See also: [scale-freeback.eu](http://scale-freeback.eu)

#### 9.3.2 Other european programs/initiatives

**Mathematical models for interacting dynamics on networks.** COST Action no. 18232, 2019-2021, PI: M.L. Delle Monache.

*Abstract:* Many physical, biological, chemical, financial or even social phenomena can be described by dynamical systems. It is quite common that the dynamics arises as a compound effect of the interaction between subsystems in which case we speak about coupled systems. This Action shall study such interactions in particular cases from three points of view: 1. the abstract approach to the theory behind these systems, 2. applications of the abstract theory to coupled structures like networks, neighbouring domains divided by permeable membranes, possibly non-homogeneous simplicial complexes, etc., 3. modelling real-life situations within this framework. The purpose of this Action is to bring together leading groups in Europe working on a range of issues connected with modelling and analysing mathematical models for dynamical systems on networks. It aims to develop a semigroup approach to various (non-)linear dynamical systems on networks as

well as numerical methods based on modern variational methods and applying them to road traffic, biological systems, and further real-life models. The Action also explores the possibility of estimating solutions and long time behaviour of these systems by collecting basic combinatorial information about underlying networks

## 9.4 National initiatives

**HANDY (Hybrid and Networked Dynamical Systems).** ANR PRC (2019-2022). Co-PI: P. Frasca.

*Abstract:* Networked dynamical systems are ubiquitous in current and emerging technologies. From energy grids, fleets of connected autonomous vehicles to online social networks, the same scenario arises in each case: dynamical units interact locally to achieve a global behavior. When considering a networked system as a whole, very often continuous-time dynamics are affected by instantaneous changes, called jumps, leading to so-called hybrid dynamical systems. Hybrid phenomena thus play an essential role in these control applications, and call upon the development of novel adapted tools for stability and performance analysis and control design. In this context, the aim of HANDY project is to provide methodological control-oriented tools for realistic networked models, which account for hybrid phenomena. The project brings together researchers from LAAS in Toulouse, CRAN in Nancy, GIPSA in Grenoble and LSS in Gif-sur-Yvette, with expertise in various domains of automatic control, ranging from geometric control and optimization, switched systems, hybrid dynamics, nonlinear control, and multi-agent systems. See also: [projects.laas.fr/handy](http://projects.laas.fr/handy)

**DOOM (Systems-theory for the Disorders Of OnlineMedia).** 80 PRIME grant from CNRS MITI (2019–2022). PI: P. Frasca.

*Abstract:* Online social media have a key role in contemporary society and the debates that take place on them are known to shape political and societal trends. For this reason, pathological phenomena like the formation of “filter bubbles” and the viral propagation of “fake news” are observed with concern. The scientific assumption of this proposal is that these information disorders are direct consequences of the inherent nature of these communication media, and more specifically of the collective dynamics of attention thereby. In order to capture these dynamics, this proposal advocates the mathematical modelling of the interplay between the medium (algorithmic component) and the users (human component). The resulting dynamics shall be explored by a system-theoretic approach, using notions such as feedback and stability. This quantitative and rigorous approach will not only unlock fundamental insights but also deliver suggestions on suitable policies to manage the media. See also: [cis.cnrs.fr/doom](http://cis.cnrs.fr/doom)

## 9.5 Regional initiatives

**ON-ROUTE** PI: A. Kibangou (2021-2024).

*Abstract:* Nowadays, millions of users regularly seek routing advice from Online Routing Applications (ORAs) like Waze, Google Maps and TomTom. Their adoption is so pervasive that ORAs have the potential to influence the patterns of congestion in traffic networks and the modal split in multimodal transportation networks. Online routing can be seen as an example of “social feedback” from the users, where information is collectively gathered from and used to influence back a complex dynamical system, whose evolution depends on the users’ choices. Online routing is in general formulated as a multicriteria optimization problem which is solved by the ORA to satisfy the user utilities, while the transportation network manager aims at optimizing some overall measure of the efficiency of the network. To fulfill its purpose, the network manager (at the level of a city, for instance, or at larger scale) has the possibility to intervene through multiple control actions (such as variable speed limits, ramp metering, access control, traffic lights) and by setting regulatory policies for the ORAs activities. It is therefore crucial for the network manager to understand the dynamics induced by ORAs in order to take adequate control actions and set effective regulatory policies. Unlike most existing projects and works, which mainly study the problem from the service providers’ points of view in order to generate smart routing or parking recommendations, we adopt the point of view of the transportation network manager that seeks to optimize the overall system.

This project therefore aims at (i) analyzing the effect of online routing on transportation network congestion; and (ii) introducing mitigation strategies against the adverse effects of ORAs through control actions (variable speed limits, ramp metering, access control, traffic lights) and regulatory policies (frequency of routing recommendations).

## 10 Dissemination

**Participants:** C. Canudas de Wit, M.L. Delle Monache, H. Fourati, P. Frasca, F. Garin, A. Kibangou.

### 10.1 Promoting scientific activities

#### 10.1.1 Scientific events: organisation

C. Canudas-de-Wit has co-organized the 1st Workshop ‘Epidemics: modeling, identification, control’, Paris, Oct. 14th, 2021

P. Frasca has co-organized the 42-nd Grenoble Summer School of Automatic Control on the topic “Data and Learning for Control”, September 6-10, 2021 ([webpage](#))

#### 10.1.2 Scientific events: selection

M. L. Delle Monache has been associate editor in the following editorial boards:

- “European Control Association (EUCA) Conference Editorial Board” (ECC) since 2020
- IEEE Intelligence Transportation Systems Conference since Jan. 2021

H. Fourati has been

- Member of the Conference Editorial Board (CEB) of the IEEE Control Systems Society (CSS), 2021-present.
- Member of the Technical Program Committee (TCP) of the International Conference on Indoor Positioning and Indoor Navigation (IPIN), Barcelona, Spain 2021.

F Garin has been Associate Editor in the following editorial boards:

- “European Control Association (EUCA) Conference Editorial Board” (ECC) since 2017

#### 10.1.3 Journal editorial activities

C. Canudas de Wit has been

- Senior Editor of the Asian Journal of Control AJC
- Senior Editor of IEEE Transactions on Control of Networks Systems IEEE-TCNS
- Editorial Advisory Board of Transportation Research part C

M. L. Delle Monache has been part of the Early Career Editorial Advisory Board (EAB) of Transportation Research part C since April 2021.

H. Fourati has been

- Associate Editor of the Asian Journal of Control
- Associate Editor of the Open Transportation Journal
- Associate Editor at the Journal of Complex Engineering Systems (CES), 2021-present.

P. Frasca has served in the editorial boards of

- Automatica, Associate Editor (2021–2024)
- IEEE Control Systems Letters, Associate Editor (2017–2021)
- Asian Journal of Control (Wiley), Associate Editor (2017–2022)

F. Garin has been Associate Editor in the following editorial board:

- IEEE Control Systems Letters since Dec. 2021

#### 10.1.4 Invited talks

- P. Frasca. “Graphons: A tool for the analysis of dynamical systems on large networks”, SSM Naples, Italy, November 25, 2021
- P. Frasca. “The closed loop between opinion formation and personalised recommendations”, Technion, Haifa, Israel, January 4, 2021
- A. Kibangu, “Transportation mode detection using AI techniques and inertial sensors”, University of Johannesburg, Johannesburg, South Africa, Nov. 5th, 2021.

#### 10.1.5 Leadership within the scientific community

**SAGIP** C. Canudas-de-Wit is member of the ‘Conseil d’Administration’ of SAGIP, the French Society of Automatic Control and Industrial Engineering

**CNU** H. Fourati is an elected member of CNU61 (Conseil National des Universités, Génie informatique, Automatique et Traitement du Signal), since 2015. The CNU61 committee oversees promotions of university lecturers all over France.

**GdR MACS** P. Frasca is member of the steering committee of the GdR MACS, a body that is funded by CNRS and coordinates national activities in Automatic Control in France, 2019–2023

**IEEE and IFAC** C. Canudas de Wit is Fellow of the IEEE and of the IFAC (International Federation of Automatic Control), both since 2016. P. Frasca is Senior member of the IEEE since 2018. Team members participate to the following technical committees of IEEE Control Systems Society and of the IFAC: IEEE-CSS Technical Committee “Networks and Communications Systems” (P. Frasca and F. Garin); IFAC Technical Committee 1.5 on Networked Systems (P. Frasca and C. Canudas de Wit); IFAC Technical Committee 2.5 on Robust Control (P. Frasca); IFAC Technical Committee 7.1 Automotive Control (C. Canudas de Wit); IFAC Technical Committee 7.4 Transportation systems (C. Canudas de Wit); IFAC TC 9.2. Systems and Control for Societal Impact (P. Frasca).

#### 10.1.6 Scientific expertise

**Advisory boards** C. Canudas-de-Wit is member of the advisory board (2017-21) of the project ‘Societal-Scale Cyber-Physical Transport Systems’ supported by the Swedish Strategic Research Foundation, KTH, Stockholm, Sweden.

#### 10.1.7 Research administration

**CE** C. Canudas-de-Wit is member of the Evaluation Committee (*Commission d’Evaluation*) of Inria (committee that oversees all hiring, promotion, and evaluation procedures for all Inria).

**HCERES** C. Canudas-de-Wit is member of the evaluation committee of LITIS laboratory, Rouen. HCERES is a nation-level evaluation held every 5 years.

**GIPSA-lab** F. Garin is ‘responsable du pôle automatique et diagnostic’ (chair of the Automatic Control and Diagnostics departement) at GIPSA-lab, since Jan 2020. A. Kibangu is an elected member of ‘Conseil de laboratoire’ of GIPSA-lab, since Jan 2020.

**Inria Grenoble** Several team members have been involved in committees at Inria Grenoble Rhône-Alpes. C. Canudas de Wit is a member of the COST-Inria-RA (Conseil d’Orientation Scientifique et Technologique, Inria Rhône-Alpes), since 2017. F. Garin has been president (since July 2019) of ‘Comité des Emplois Scientifiques’ (post-docs and ‘délégations’). M. L. Delle Monache has been a member of ‘Comité des Études Doctorales’ (PhD grants) and ‘Commission de développement technologique’ (research engineers).

**Persyval-lab** F. Garin has been member of the research committee of PERSYVAL-Lab LabEx as co-leader of the research axis on cyber-physical systems (since 2019).

**UGA** A. Kibangou is in his second term as an elected member of “Conseil du pôle MSTIC” at Univ. Grenoble Alpes. He has been member of this council since 2016. H. Fourati is member of “Conseil documentaire” of University Grenoble Alpes representing the discipline “Sciences and technologies”, 2020-2023.

## 10.2 Teaching - Supervision - Juries

### 10.2.1 Teaching

H. Fourati gives each year around 250h of lectures and labs on average for first and second year students at the electrical engineering department (GEII) of IUT1, and third year students of bachelor’s degree at Univ. Grenoble Alpes. The courses include Mathematics, logics, networks and automatic control.

P. Frasca has lectured about Intelligent Transportation Systems & Coordination of Autonomous Vehicles in the Master Autonomous and Robotics Systems (MARS) of the University of Grenoble (4h in 2021).

F. Garin gives each year a class ‘Distributed Algorithms and Network Systems’, 13.5h, M2, Univ. Grenoble Alpes.

A. Kibangou gives each year 250h of lectures and labs on average for first and second year students at the electrical engineering department (GEII) of IUT1 at Univ. Grenoble Alpes. The courses include Control theory and Mathematics.

### 10.2.2 Supervision

- PhD: Thembani Moyo, Sustainability of urban public transport through ecological traffic management: the case of Johannesburg, South Africa, University of South Africa, December 2021, co-advised by A. Kibangou and W. Musakwa (Univ. of Johannesburg).
- PhD: Muhammad Umar B. Niazi, Aggregated monitoring of large-scale network systems and control of epidemics, Univ. Grenoble Alpes, July 2021, co-advised by C. Canudas de Wit and A. Kibangou.
- PhD: Denis Nikitin, Scalable Large-Scale Control of Network Aggregates, Univ. Grenoble Alpes, September 2021, co-advised by C. Canudas de Wit and P. Frasca.
- PhD: Bassel Othman, Variable speed limits and signalized access control in an urban road network for improved environmental sustainability, Univ. Grenoble Alpes, October 2021, co-advised by C. Canudas de Wit and G. De Nunzio (IFPEN).
- PhD: Martin Rodriguez-Vega, Optimal Sensor Placement And Density Estimation In Large-Scale Traffic Networks, Univ. Grenoble Alpes, April 2021, co-advised by C. Canudas de Wit and H. Fourati.
- PhD: Nigina Toktassynova, Simulation and research of control system of phosphorite ore sintering process, Kazakh National Research Technical University, December 2021, co-advised by B. Suleimenov (Kazakh National Research Technical Univ.) and H. Fourati.
- PhD: Liudmila Tumash, Traffic control in large-scale urban networks, Univ. Grenoble Alpes, September 2021, co-advised by C. Canudas de Wit and M. L. Delle Monache.
- PhD: Makia Zmitri, Magnetometer array-based indoor navigation using Kalman filter, Univ. Grenoble Alpes, September 2021, co-advised by H. Fourati and C. Prieur.

- PhD in progress: Tommaso Toso, Online Routing Recommendations in Multimodal Transportation Networks, from October 2021, co-advised by A. Kibangou and P. Frasca.
- PhD in progress: Nomfundo Cele, Perception of Quality of Service on public transportation in developing countries, from November 2020, co-advised by A. Kibangou and W. Musakwa (Univ. of Johannesburg).
- PhD in progress: Nassim Bouarour, User behavior and recommendation systems, from Oct. 2020, co-advised by Sihem Amer-Yahia (LIG Grenoble), Idir Benouaret (LIG Grenoble) and P. Frasca.
- PhD in progress: Tarso Kraemer Sarzi Sartori, Mitigation of radiation effects on the attitude estimation processing of autonomous things, from Oct. 2020, co-advised by R. Possamai Bastos (TIMA Grenoble) and H. Fourati.
- PhD in progress: Maria Castaldo, Disorders of online media, from Nov. 2019, co-advised with Tommaso Venturini (Centre Internet et Société, CNRS)
- PhD in progress: Pierre Gogendreau, Smart integrated system for geolocation based on multiples heterogeneous and transitory information sources, Univ. Montpellier, from Sept. 2019, co-advised by Serge Bernard (LIRMM Montpellier), Sylvain Bonhommeau (IFREMER) and H. Fourati
- PhD in progress: Renato Vizuete, Open Multi-Agent Systems, from Sept. 2019, co-advised with Elena Panteley
- PhD in progress: Ujjwal Pratap, Resilient control in scale-free networks, from Feb. 2019, co-advised by C. Canudas de Wit, F. Garin, and H. Sandberg (KTH Stockholm).

## 10.3 Popularization

### 10.3.1 Articles and contents

Interview by Marie Lyan, La Tribune–Auvergne-Rhône-Alpes, about Covid-19 research published in PLOS Computational Biology, 2021.

### 10.3.2 Interventions

M. L. Delle Monache gave a talk to students of 8th grade (4ème) and 11th Grade (1ère) in the Cérémonie de remise de prix des Olympiades de Mathématiques, La mobilité et les véhicules autonomes, Université Grenoble Alpes, France, June 2021.

## 11 Scientific production

### 11.1 Major publications

- [1] V. Giammarino, S. Baldi, P. Frasca and M. L. Delle Monache. ‘Traffic Flow on a Ring With a Single Autonomous Vehicle: An Interconnected Stability Perspective’. In: *IEEE Transactions on Intelligent Transportation Systems* 22.8 (Aug. 2021), pp. 4998–5008. DOI: [10.1109/TITS.2020.2985680](https://doi.org/10.1109/TITS.2020.2985680). URL: <https://hal.inria.fr/hal-03011895>.
- [2] M. U. B. Niazi, C. Canudas de Wit and A. Kibangou. ‘Average State Estimation in Large-scale Clustered Network Systems’. In: *IEEE Transactions on Control of Network Systems* 7.4 (Dec. 2020), pp. 1736–1745. DOI: [10.1109/TCNS.2020.2999304](https://doi.org/10.1109/TCNS.2020.2999304). URL: <https://hal.archives-ouvertes.fr/hal-02524982>.
- [3] D. Nikitin, C. Canudas de Wit and P. Frasca. ‘Control of Average and Deviation in Large-Scale Linear Networks’. In: *IEEE Transactions on Automatic Control* (2021). DOI: [10.1109/TAC.2021.3065191](https://doi.org/10.1109/TAC.2021.3065191). URL: <https://hal.archives-ouvertes.fr/hal-03170606>.

- [4] R. Vizuete, F. Garin and P. Frasca. ‘The Laplacian Spectrum of Large Graphs Sampled from Graphons’. In: *IEEE Transactions on Network Science and Engineering* 8.2 (2021), pp. 1711–1721. DOI: [10.1109/TNSE.2021.3069675](https://doi.org/10.1109/TNSE.2021.3069675). URL: <https://hal-centralesupelec.archives-ouvertes.fr/hal-03197046>.
- [5] M. Zmitri, H. Fourati and C. Prieur. ‘Magnetic Field Gradient-Based EKF for Velocity Estimation in Indoor Navigation’. In: *Sensors* 20.20 (Oct. 2020), pp. 1–17. DOI: [10.3390/s20205726](https://doi.org/10.3390/s20205726). URL: <https://hal.archives-ouvertes.fr/hal-03138331>.

## 11.2 Publications of the year

### International journals

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