IN PARTNERSHIP WITH:
CNRS

Institut polytechnique de Grenoble

Université de Grenoble Alpes

Activity Report 2018

Project-Team NECS

Networked Controlled Systems

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

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Optimization and control of dynamic systems

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Project-Team NECS

Creation of the Project-Team: 2007 January 01, end of the Project-Team: 2018 December 31

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Other Research Topics and Application Domains:

B7. - Transport and logistics
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2. Overall Objectives

2.1. Context and overall goal of the project

NECS is a joint INRIA/GIPSA-LAB team, bi-located at the INRIA-Rhône-Alpes Center in Montbonnot and at GIPSA-LAB (http://www.gipsa-lab.grenoble-inp.fr) in the Saint-Martin-d'Hères campus, both locations being in the Grenoble area. NECS team's research is focused on Networked Controlled Systems.
The research field of Networked Controlled Systems deals with feedback systems controlled over networks, but also concerns systems that naturally exhibit a network structure (e.g., traffic, electrical networks, etc.).

The first system category results from the arrival of new control problems posed by the consideration of several factors, such as: new technological components (e.g., wireless, RF, communications, local networks, etc.), increase of systems complexity (e.g., increase in vehicle components), the distributed location of sensor and actuator, and computation constraints imposed by their embedded nature. In this class of systems, the way that the information is transferred and processed (information constraints), and the manner in which the computation resources are used (resources management), have a substantial impact in the resulting stability and performance properties of the feedback controlled systems. One main challenge here is the co-design of control together with one or more other components of different nature. The NECS team has tackled co-design problems concerning:

- Control under communications and network constraints;
- Control under resources constraints.

The second category of systems is motivated by the natural network structure in which the original systems are built. Examples are biologic networks, traffic networks, and electrical networks. The complex nature of such systems makes the classical centralized view of the control design obsolete. New distributed and/or collaborative control and estimation algorithms need to be devised as a response to this complexity. Even if the dynamic behavior of each individual system is still important, the aggregated behavior (at some macroscopic level), and its interconnection graph properties become of dominant importance. To build up this research domain, the team has put a strong focus on traffic (vehicular) networks, and in some associated research topics capturing problems that are specific to these complex network systems (distributed estimation, graph-discovering, etc).

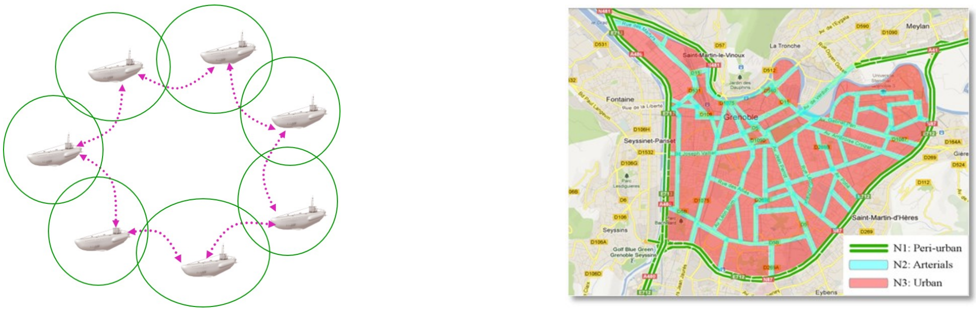

Figure 1. Left: a system of autonomous agents, where the network structure is created by the feedback, used to coordinate agents towards a common goal. Right: a system naturally having a network structure.

3. Research Program

3.1. Introduction

NECS team deals with Networked Control Systems. Since its foundation in 2007, the team has been addressing issues of control under imperfections and constraints deriving from the network (limited computation resources of the embedded systems, delays and errors due to communication, limited energy resources), proposing co-design strategies. The team has recently moved its focus towards general problems on *control of network systems*, which involve the analysis and control of dynamical systems with a network structure or whose operation is supported by networks. This is a research domain with substantial growth and is now recognized as a priority sector by the IEEE Control Systems Society: IEEE has started a new journal, IEEE Transactions on Control of Network Systems, whose first issue appeared in 2014.

More in detail, the research program of NECS team is along lines described in the following sections.

3.2. Distributed estimation and data fusion in network systems

This research topic concerns distributed data combination from multiple sources (sensors) and related information fusion, to achieve more specific inference than could be achieved by using a single source (sensor). It plays an essential role in many networked applications, such as communication, networked control, monitoring, and surveillance. Distributed estimation has already been considered in the team. We wish to capitalize and strengthen these activities by focusing on integration of heterogeneous, multidimensional, and large data sets:

- Heterogeneity and large data sets. This issue constitutes a clearly identified challenge for the future. Indeed, heterogeneity comes from the fact that data are given in many forms, refer to different scales, and carry different information. Therefore, data fusion and integration will be achieved by developing new multi-perception mathematical models that can allow tracking continuous (macroscopic) and discrete (microscopic) dynamics under a unified framework while making different scales interact with each other. More precisely, many scales are considered at the same time, and they evolve following a unique fully-integrated dynamics generated by the interactions of the scales. The new multi-perception models will be integrated to forecast, estimate and broadcast useful system states in a distributed way. Targeted applications include traffic networks and navigation.
- Multidimensionality. This issue concerns the analysis and the processing of multidimensional data, organized in multiway array, in a distributed way. Robustness of previously-developed algorithms will be studied. In particular, the issue of missing data will be taken into account. In addition, since the considered multidimensional data are generated by dynamic systems, dynamic analysis of multiway array (or tensors) will be considered. The targeted applications concern distributed detection in complex networks and distributed signal processing for collaborative networks. This topic is developed in strong collaboration with UFC (Brazil).

3.3. Network systems and graph analysis

This is a research topic at the boundaries between graph theory and dynamical systems theory.

A first main line of research will be to study complex systems whose interactions are modeled with graphs, and to unveil the effect of the graph topology on system-theoretic properties such as observability or controllability. In particular, on-going work concerns observability of graph-based systems: after preliminary results concerning consensus systems over distance-regular graphs, the aim is to extend results to more general networks. A special focus will be on the notion of 'generic properties', namely properties which depend only on the underlying graph describing the sparsity pattern, and hold true almost surely with a random choice of the non-zero coefficients. Further work will be to explore situations in which there is the need for new notions different from the classical observability or controllability. For example, in opinion-forming in social networks or in formation of birds flocks, the potential leader might have a goal different from classical controllability. On the one hand, his goal might be much less ambitious than the classical one of driving the system to any possible state (e.g., he might want to drive everybody near its own opinion, only, and not to any combination of different individual opinions), and on the other hand he might have much weaker tools to construct his control input (e.g., he might not know the whole system's dynamics, but only some local partial information). Another example is the question of detectability of an unknown input under the assumption that such an input has a sparsity constraint, a question arising from the fact that a cyber-physical attack might be modeled as an input aiming at controlling the system's state, and that limitations in the capabilities of the attacker might be modeled as a sparsity constraint on the input.

A second line of research will concern graph discovery, namely algorithms aiming at reconstructing some properties of the graph (such as the number of vertices, the diameter, the degree distribution, or spectral properties such as the eigenvalues of the graph Laplacian), using some measurements of quantities related to a dynamical system associated with the graph. It will be particularly challenging to consider directed graphs, and to impose that the algorithm is anonymous, i.e., that it does not makes use of labels identifying the different agents associated with vertices.

3.4. Collaborative and distributed network control

This research line deals with the problem of designing controllers with a limited use of the network information (i.e. with restricted feedback), and with the aim to reach a pre-specified global behavior. This is in contrast to centralized controllers that use the whole system information and compute the control law at some central node. Collaborative control has already been explored in the team in connection with the underwater robot fleet, and to some extent with the source seeking problem. It remains however a certain number of challenging problems that the team wishes to address:

- Design of control with limited information, able to lead to desired global behaviors. Here the graph structure is imposed by the problem, and we aim to design the "best" possible control under such a graph constraint [1]. The team would like to explore further this research line, targeting a better understanding of possible metrics to be used as a target for optimal control design. In particular, and in connection with the traffic application, the long-standing open problem of ramp metering control under minimum information will be addressed.
- Clustering control for large networks. For large and complex systems composed of several sub-networks, feedback design is usually treated at the sub-network level, and most of the times without taking into account natural interconnections between sub-networks. The team is exploring new control strategies, exploiting the emergent behaviors resulting from new interconnections between the network components. This requires first to build network models operating in aggregated clusters, and then to re-formulate problems where the control can be designed using the cluster boundaries rather than individual control loops inside of each network. Examples can be found in the transportation application domain, where a significant challenge will be to obtain dynamic partitioning and clustering of heterogeneous networks in homogeneous sub-networks, and then to control the perimeter flows of the clusters to optimize the network operation. This topic is at the core of the Advanced ERC project Scale-FreeBack.

3.5. Transportation networks

This is currently the main application domain of the NECS team. Several interesting problems in this area capture many of the generic networks problems identified before (e.g., decentralized/collaborative traffic optimal control, density balancing using consensus concepts, data fusion, distributed estimation, etc.). Several specific actions have been continued/launched to this purpose: improvement and finalization of the Grenoble Traffic Lab(GTL), EU projects (SPEEDD, ERC-AdG Scale-FreeBack). Further research goals are envisioned, such as:

- Modeling of large scale traffic systems. We aim at reducing the complexity of traffic systems modeling by engaging novel modeling techniques that make use of clustering for traffic networks while relying on its specific characteristics. Traffic networks will be aggregate into clusters and the main traffic quantities will be extrapolated by making use of this aggregation. Moreover, we are developing an extension of the Grenoble Traffic Lab (GTL) for downtown Grenoble which will make use of GPS and probe data to collect traffic data in the city center.
- Modeling and control of intelligent transportation systems. We aim at developing a complete micro-macro modeling approach to describe and model the new traffic dynamics that is developing thanks to mixed (simple, connected and automated) vehicles in the roads. This will require cutting edge mathematical theory and field experiments.

4. Application Domains

4.1. A large variety of application domains

Sensor and actuator networks are ubiquitous in modern world, thanks to the advent of cheap small devices endowed with communication and computation capabilities. Potential application domains for research in networked control and in distributed estimation are extremely various, and include the following examples.

- 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.

[1] Such a problem has been previously addressed in some specific applications, particularly robot fleets, and only few recent theoretical works have initiated a more systematic system-theoretic study of sparsity-constrained system realization theory and of sparsity-constrained feedback control.

- Smart grids: the operation of electrical networks is changing from a centralized optimization framework towards more distributed and adaptive protocols, due to the high number of small local energy producers (e.g., solar panels on house roofs) that now interact with the classic large power-plants.
- Disaster relief operations, where data collected by sensor networks can be used to guide the actions of human operators and/or to operate automated rescue equipment.
- Surveillance using swarms of Unmanned Aerial Vehicles (UAVs), where sensor information (from sensors on the ground and/or on-board) can be used to guide the UAVs to accomplish their mission.
- Environmental monitoring and exploration using self-organized fleets of Autonomous Underwater Vehicles (AUVs), collaborating in order to reach a goal such as finding a pollutant source or tracing a seabed map.
- 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 threats.

In particular, NECS team is currently focusing in the areas described in detail below.

4.2. 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. The research activity is on two main challenges: (1) modeling and forecasting, so as to provide accurate information to users, e.g., travel times; and (2) control, via ramp-metering and/or variable speed limits. The Grenoble Traffic Lab (see http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php) is an experimental platform, collecting traffic infrastructure information in real time from Grenoble South Ring, together with innovative software e.g. for travel-time prediciton, and a show-case where to graphically illustrate results to the end-user. This activity is done in close collaboration with local traffic authorities (DIR-CE, CG38, La Metro), and with the start-up company Karrus (http://www.karrus-its.com/)

4.3. Inertial navigation

The team is exploring techniques and approaches from estimation, filtering and machine learning, in order to use inertial sensor units in pedestrian navigation, attitude estimation, augmented reality and human activities recognition. These units are composed of accelerometers, magnetometers and gyroscopes, sensors that we find usually in smartphones. This area of research in the team will evolve towards multimodal navigation, cooperative and collaborative navigation in indoor and outdoor environments.

5. Highlights of the Year

5.1. Highlights of the Year

- The team organized the international ERC Scale-FreeBack workshop on “Analysis and Control of Large-Scale Complex Networks”, Grenoble, September 10-11th, 2018 (http://scale-freeback.eu/workshop-on-analysis-and-control-of-large-scale-complex-networks-10-11-sept-2018-grenoble/)
- P. Frasca is Senior Member of the IEEE

6. New Software and Platforms

6.1. GTL

Grenoble Traffic Lab

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

- 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, Rémi Piotaix, Rohit Singhal and Vadim Bertrand
- Contact: Carlos Canudas-De-Wit
- URL: http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php

6.2. Benchmarks Attitude Smartphones

KEYWORDS: Experimentation - Motion analysis - Sensors - Performance analysis - Smartphone
SCIENTIFIC DESCRIPTION: We investigate the precision of attitude estimation algorithms in the particular context of pedestrian navigation with commodity smartphones and their inertial/magnetic sensors. We report on an extensive comparison and experimental analysis of existing algorithms. We focus on typical motions of smartphones when carried by pedestrians. We use a precise ground truth obtained from a motion capture system. We test state-of-the-art attitude estimation techniques with several smartphones, in the presence of magnetic perturbations typically found in buildings. We discuss the obtained results, analyze advantages and limits of current technologies for attitude estimation in this context. Furthermore, we propose a new technique for limiting the impact of magnetic perturbations with any attitude estimation algorithm used in this context. We show how our technique compares and improves over previous works.

- Participants: Hassen Fourati, Nabil Layaïda, Pierre Genevès and Thibaud Michel
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- URL: http://tyrex.inria.fr/mobile/benchmarks-attitude/

7. New Results

7.1. Network systems: modeling, analysis, and estimation

7.1.1. Network reduction towards a scale-free structure preserving physical properties

Participants: N. Martin, P. Frasca, C. Canudas de Wit [Contact person].

In the context of the ERC project, we are addressing a problem of graph reduction, where a given arbitrary weighted graph is reduced to a (smaller) scale-free graph while preserving a consistency with the initial graph and some physical properties. This problem can be formulated as a minimization problem. We give specifications to this general problem to treat a particular case: to this end we define a metric to measure the scale-freeness of a graph and another metric to measure the similarity between two graphs with different dimensions, based on a notion of spectral centrality. Moreover, through the reduction we also preserve a property of mass conservation (essentially, Kirchoff's first law). We study the optimization problem and, based on the gained insights, we derive an algorithm allowing to find an approximate solution. Finally, we have simulated the algorithm both on synthetic networks and on real-world examples of traffic networks that represent the city of Grenoble. These results are presented in [57] and in [31]. We also developed an application to the control of epidemics [58].

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

Participants: F. Garin [Contact person], A. Kibangou, S. Gracy.

Cyber-physical systems are composed of many simple components (agents) with interconnections giving rise to a global complex behaviour. Interesting recent research has been exploring how the graph describing interactions affects control-theoretic properties such as controllability or observability, namely answering the question whether a small group of agents would be able to drive the whole system to a desired state, or to retrieve the state of all agents from the observed local states only.

A related problem is observability in the presence of an unknown input, where the input can represent a failure or a malicious attack, aiming at disrupting the normal system functioning while staying undetected. 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 obtain two kinds of results (see [24], [25] and the PhD thesis of S. Gracy): structural results, true for almost all interaction weights, and strongly structural results, true for all non-zero interaction weights. We consider both the case where the system graph is time-invariant, and the case where it varies in time.

When the conditions for ISO are satisfied, one can run algorithms in the same vein as a Kalman filter, in order to reconstruct the state and the unknown input from noisy measurements. These algorithms are known for the case where the input can be reconstructed with only one time-step of delay with respect to the measurements; in [54] we propose a (suboptimal) filter for the case when this is not possible, i.e., more measurements are needed for the input reconstruction.

7.1.3. Heterogeneity and uncertainty in distributed estimation from relative measurements

Participants: C. Ravazzi, N. K. Chan, P. Frasca [Contact person].

This work, presented in [34], has studied the problem of estimation from relative measurements in a graph, in which a vector indexed over the nodes has to be reconstructed from pairwise measurements of differences between its components associated to nodes connected by an edge. In order to model heterogeneity and uncertainty of the measurements, we assume them to be affected by additive noise distributed according to a Gaussian mixture. In this original setup, we formulate the problem of computing the Maximum-Likelihood (ML) estimates and we design two novel algorithms, based on Least Squares regression and Expectation-Maximization (EM). The first algorithm (LSEM) is centralized and performs the estimation from relative measurements, the soft classification of the measurements, and the estimation of the noise parameters. The second algorithm (Distributed LS-EM) is distributed and performs estimation and soft classification of the measurements, but requires the knowledge of the noise parameters. We provide rigorous proofs of convergence for both algorithms and we present numerical experiments to evaluate their performance and compare it with solutions from the literature. The experiments show the robustness of the proposed methods against different kinds of noise and, for the Distributed LS-EM, against errors in the knowledge of noise parameters.

7.1.4. Average state estimation in large-scale multi-cluster networks

Participants: U. Niazi, A. Kibangou, C. Canudas de Wit [Contact person].

In the context of the ERC project, we are addressing the problem of estimation of a functional of non-observed states. Indeed, large-scale network systems can be unobservable from the dedicated state measurements at few nodes. By resorting to an aggregation of multiple clusters of unmeasured nodes, we are investigating the observability and detectability of average states of the clusters. The approach is to obtain a reduced network system whose state vector contains the average states of the clusters. The notion of average observability is defined with respect to the observability of this reduced network system. For average observability, we have stated a necessary condition and a sufficient condition depending solely on the structure of the network. Average detectability, which is a milder notion than average observability, is also studied and a sufficient condition, under which an open-loop average state observer converges, is provided. This condition requires clusters of unmeasured nodes to have negatively balanced local outflow centrality.

7.2. Control of multi-agent systems and opinion dynamics

7.2.1. Open multi-agent systems: Dynamic consensus

Participants: W. S. Rossi, P. Frasca [Contact person].

In [53] we investigate a dynamic consensus problem for an open multi-agent system. Open multi-agent systems are characterized by a time-varying set of agents connected by a network: agents may leave and new agents may join the network at any time, thus the term "open". The dynamic consensus problem consists in achieving agreement about the time-varying average of a set of reference signals that are assumed to be the agents' inputs. Dynamic consensus has recently found application in the context of distributed estimation for electric demand-side management, where a large population of connected domestic appliances needs to estimate its future average power consumption. Since the considered network of devices changes as new appliances log in and out, there is a need to develop and characterize dynamic consensus algorithms for these open scenarios. In this paper we give several initial contributions both to a general theory of open multi-agent systems and to the specific problem of dynamic consensus within this context. On the theoretical side, we propose a formal definition of open multi-agent system, a suitable notion of stability, and some sufficient conditions to establish it. On the applied side, we design a novel dynamic consensus algorithm, the Open Proportional Dynamic Consensus algorithm. We characterize some of its convergence properties in the proposed open-multi-agent systems framework and we illustrate its evolution by numerical simulations.

7.2.2. Robust average consensus over unreliable networks

Participants: F. Acciani, P. Frasca [Contact person], G. Heijenk, A. Stoorvogel.

Packet loss is a serious issue in wireless consensus networks, as even few failures might prevent a network to converge to the desired consensus value. In the last four years, we have devised some possible ways to compensate for the errors caused by packet collisions, by modifying the updating weights. Since these modifications may result in a reduced convergence speed, a gain parameter is used to increase the convergence speed, and an analysis of the stability of the network is performed, leading to a criterion to choose such gain to guarantee network stability. For the implementation of the compensation method, we propose a new communication algorithm, which uses both synchronous and asynchronous mechanisms to achieve average consensus and to deal with uncertainty in packet delivery. The paper [14] provides a complete account of our results.

7.2.3. Asynchronous opinion dynamics on the k-nearest-neighbors graph

Participants: W. S. Rossi, P. Frasca [Contact person].

This work is about a new model of opinion dynamics with opinion-dependent connectivity. We assume that agents update their opinions asynchronously and that each agent's new opinion depends on the opinions of the k agents that are closest to it. In the paper [63], we show that the resulting dynamics is substantially different from comparable models in the literature, such as bounded-confidence models. We study the equilibria of the dynamics, observing that they are robust to perturbations caused by the introduction of new agents. We also prove that if the number of agents n is smaller than 2k, the dynamics converge to consensus. This condition is only sufficient.

7.2.4. Quantization effects in opinion dynamics

Participants: F. Ceragioli, P. Frasca [Contact person].

This work deals with continuous-time opinion dynamics that feature the interplay of continuous opinions and discrete behaviors. In our model, the opinion of one individual is only influenced by the behaviors of fellow individuals. The key technical difficulty in the study of these dynamics is that the right-hand sides of the equations are discontinuous and thus their solutions must be intended in some generalized sense: in our analysis, we consider both Carathéodory and Krasovskii solutions. We first prove the existence and completeness of Carathéodory solutions from every initial condition and we highlight a pathological behavior of Carathéodory solutions, which can converge to points that are not (Carathéodory) equilibria. Notably, such points can be arbitrarily far from consensus and indeed simulations show that convergence to nonconsensus configurations is common. In order to cope with these pathological attractors, we study Krasovskii solutions. We give an estimate of the asymptotic distance of all Krasovskii solutions from consensus and we prove its tightness by an example of equilibrium such that this distance is quadratic in the number of agents. This fact implies that quantization can drastically destroy consensus. However, consensus is guaranteed in some special cases, for instance, when the communication among the individuals is described by either a complete or a complete bipartite graph. These results are reported in details in [19], whereas the book chapter [66] puts them in the broader context of consensus-seeking dynamics with discontinuous right-hand side.

7.2.5. *Message-passing computation of harmonic influence in social networks*

Participants: W. S. Rossi, P. Frasca [Contact person].

In the study of networks, identifying the most important nodes is of capital importance. The concept of Harmonic Influence has been recently proposed as a metric for the importance of nodes in a social network. This metric evaluates the ability for one node to sway the opinions of the other nodes in the network, under the assumption of a linear diffusion of opinions in the network. A distributed message passing algorithm for its computation has been proposed by Vassio et al., 2014, but its convergence guarantees were limited to trees and regular graphs. In [36], we prove that the algorithm converges on general graphs. In [64], we offer two additional contributions to its study. We evaluate how the presence of communities in the network impacts the algorithm performance, and how the algorithm performs on networks which change topology during the execution of the algorithm.

7.2.6. *Distributed control and game theory: self-optimizing systems*

Participants: F. Garin [Contact person], B. Gaujal [POLARIS], S. Durand.

The design of distributed algorithms for a networked control system composed of multiple interacting agents, in order to drive the global system towards a desired optimal functioning, can benefit from tools and algorithms from game theory. This is the motivation of the Ph.D. thesis of Stéphane Durand, a collaboration between POLARIS and NECS teams.

The focus of this thesis is on the complexity of the best response algorithm to find a Nash equilibrium for potential games. Best response is a simple greedy algorithm, known to converge to a Nash equilibrium if players play one after the other in a round-robin way, but with a worst-case complexity which is exponential in the number of players. We consider instead its average complexity over the ensemble of random potential games, showing that such average complexity is surprisingly low, only linear in the number of players. Then we focus on removing the need of a centralised scheduler enforcing the round robin order of play. In [52], [21] we consider agents activated according to independent local Poisson clocks, and we show that (despite the possible overlaps of the computations of some players), we can still obtain convergence, with an average complexity of order $n \log n / \log \log n$, where n is the number of players. In [51] we show how to take advantage of the structure of the interactions between players in a network game: noninteracting players can play simultaneously. This improves best response algorithm, both in the centralized and in the distributed case.

7.2.7. *Control of switched interconnected large-scale systems*

Participants: H. Fourati [Contact person], D. Belkhiat, D. Jabri.

We proposed in [27] a new design of a decentralized output-feedback tracking control for a class of switched large-scale systems with external bounded disturbances. The controller proposed herein is synthesized to satisfy the robust H_∞ tracking performance with local disturbance attenuation levels. Based on multiple switched Lyapunov functions, sufficient conditions proving the existence of the proposed controller are formulated in terms of Linear Matrix Inequalities (LMI).

7.3. Transportation networks and vehicular systems

7.3.1. *Density and flow reconstruction in urban traffic networks*

Participants: C. Canudas de Wit [Contact person], H. Fourati, A. Kibangou, A. Ladino, M. Rodriguez-Vega.

In [56], we consider the problem of joint reconstruction of flow and density in a urban traffic network using heterogeneous sources of information. The traffic network is modeled within the framework of macroscopic traffic models, where we adopt Lighthill-Whitham-Richards model (LWR) conservation equation characterized by a piecewise linear fundamental diagram. The estimation problem considers two key principles. First, the error minimization between the measured and reconstructed flows and densities, and second the equilibrium state of the network which establishes flow propagation within the network. Both principles are integrated together with the traffic model constraints established by the supply/demand paradigm. Finally the problem is cast as a constrained quadratic optimization with equality constraints in order to shrink the feasible region of estimated variables. Some simulation scenarios based on synthetic data for a manhattan grid network are provided in order to validate the performance of the proposed algorithm.

In [62], we addressed the conditions imposed on the number and location of fixed sensors such that all flows in the network can be uniquely reconstructed. We determine the minimum number of sensors needed to solve the problem given partial information of turning ratios, and then we propose a linear time algorithm for their allocation in a network. Using these results in addition to floating car data, we propose a method to reconstruct all traffic density and flow.

7.3.2. Discrete-time system optimal dynamic traffic assignment (SO-DTA) with partial control for horizontal queuing networks

Participants: S. Samaranayake, J. Reilly, W. Krichene, M. L. Delle Monache [Contact person], P. Goatin [Acumes, Inria], A. Bayen.

Dynamic traffic assignment (DTA) is the process of allocating time-varying origin-destination (OD) based traffic demand to a set of paths on a road network. There are two types of traffic assignment that are generally considered, the user equilibrium or Wardrop equilibrium allocation (UE-DTA), in which users minimize individual travel-time in a selfish manner, and the system optimal allocation (SODTA) where a central authority picks the route for each user and seeks to minimize the aggregate total travel-time over all users. It can be shown that the price of anarchy (PoA), the worst-case ratio of the system delay caused by the selfish behavior over the system optimal solution, may be arbitrarily large even in simple networks. System optimal (SO) traffic assignment on the other hand leads to optimal utilization of the network resources, but is hard to achieve in practice since the overriding objective for individual drivers in a road network is to minimize their own travel-time. It is well known that setting a toll on each road segment corresponding to the marginal delay of the demand moves the user equilibrium towards a SO allocation. In [37], we formulate the system optimal dynamic traffic assignment problem with partial control (SO-DTAPC), using a Godunov discretization of the Lighthill-Williams-Richards (LWR) partial differential equation (PDE) with a triangular flux function. We propose solving the SO-DTA-PC problem with the non-convex traffic dynamics and limited OD data with complete split ratios as a non-linear optimal control problem. This formulation generalizes to multiple sources and multiple destinations. We show that the structure of our dynamical system allows for very efficient computation of the gradient via the discrete adjoint method.

7.3.3. Priority-based Riemann solver for traffic flow on networks

Participants: M. L. Delle Monache [Contact person], P. Goatin [Acumes, Inria], B. Piccoli.

In [20] we introduce a novel solver for traffic intersection which considers priorities among the incoming roads as the first criterion and maximization of flux as the second. The main idea is that the road with the highest priority will use the maximal flow taking into account also outgoing roads constraints. If some room is left for additional flow then the road with the second highest priority will use the left space and so on. A precise definition of the new Riemann solver, called Priority Riemann Solver, is based on a traffic distribution matrix , a priority vector and requires a recursion method. The general existence theorem for Riemann solvers on junctions can not be applied in the present case.Therefore, we achieve existence via a new set of general properties.

7.3.4. Dissipation of stop-and-go waves via control of autonomous vehicles

Participants: R. Stern, S. Cui, M. L. Delle Monache [Contact person], R. Bhadani, M. Bunting, M. Churchill, N. Hamilton, R. Haulcy, H. Pohlmann, F. Wu, B. Piccoli, B. Seibold, J. Sprinkle, D. B. Work.

Traffic waves are phenomena that emerge when the vehicular density exceeds a critical threshold. Considering the presence of increasingly automated vehicles in the traffic stream, a number of research activities have focused on the influence of automated vehicles on the bulk traffic flow. In [38], we demonstrate experimentally that intelligent control of an autonomous vehicle is able to dampen stop-and-go waves that can arise even in the absence of geometric or lane changing triggers. Precisely, our experiments on a circular track with more than 20 vehicles show that traffic waves emerge consistently, and that they can be dampened by controlling the velocity of a single vehicle in the flow. We compare metrics for velocity, braking events, and fuel economy across experiments. These experimental findings suggest a paradigm shift in traffic management: flow control will be possible via a few mobile actuators (less than 5%) long before a majority of vehicles have autonomous capabilities.

7.3.5. Cooperative adaptive cruise control over unreliable networks

Participants: F. Acciani, P. Frasca [Contact person], G. Heijenk, E. Semsar-Kazerooni, A. Stoorvogel.

Cooperative Adaptive Cruise Control (CACC) is a promising technique to increase highway throughput, safety and comfort for vehicles. Enabled by wireless communication, CACC allows a platoon of vehicles to achieve better performance than Adaptive Cruise Control; however, since wireless is employed, problems related to communication unreliability arise. In [45], we design a digital controller to achieve platoon stability, enhanced by an observer to increase robustness against packet losses. Our results confirms the interest of using an observer in combination with a local and cooperative digital controller.

7.3.6. Heterogeneity in synchronization: an adaptive control approach, with applications to vehicle platooning

Participants: S. Baldi, P. Frasca [Contact person].

Heterogeneity is a substantial obstacle to achieve synchronisation of interconnected systems (that is, in control) In order to overcome heterogeneity, advanced control techniques are needed, such as the use of "internal models" or of adaptive techniques. In a series of papers motivated by multi-vehicle platooning and coordinated autonomous driving, we have explored the application of adaptive control techniques. Our results cover both the cases of state-feedback [15] and of output-feedback [16], under the assumption that the topology of the interconnections has no circuits. Further investigation has shown that restrictive assumption can be relaxed (at least for state-feedback on some specific topologies) [47]. This understanding paves the road to use these techniques not only to stabilise heterogeneous platoons, but also to manage their merging or splitting operations [48].

7.3.7. Modeling traffic on roundabout

Participants: M. L. Delle Monache [Contact person], A. Rat, S. Hammond, B. Piccoli.

In [50] we introduce a Riemann solver for traffic flow on a roundabout with two lanes. The roundabout is modeled as a sequence of junctions. The Riemann solver provides a solution at junctions by taking into consideration traffic distribution, priorities, and the maximization of through flux. We prove existence and uniqueness of the solution of the Riemann problem and show some results numerically. This work stems from the fact that there is a general notion among transportation professionals that having a longer additional lane length at a double-lane roundabout entry yields better performances. In [55], we investigate this notion using Lighthill-Whitham-Richards Model. Using Lighthill- Whitham-Richards model, a double-lane roundabout with additional lane design at the entry is analyzed. The additional lane lengths are varied at the entry in order to study the effect of different additional lane lengths on roundabout performance. The results obtained with the PDE model were then compared with similar lane length variations in VISSIM.

7.3.8. Two dimensional models for traffic

Participants: S. Mollier, M. L. Delle Monache, C. Canudas de Wit [Contact person], B. Seibold.

The work deals with the problem of modeling traffic flow in urban area, e. g. a town. More precisely, the goal is to design a two-dimensional macroscopic traffic flow model suitable to model large network as the one of a city. Macroscopic traffic models are inspired from fluid dynamic. They represent vehicles on the road by a density and describe their evolution with partial differential equations. Usually, these models are one dimensional models and, for instance, give a good representation of the evolution of traffic states in highway. The extension of these 1D models to a network is possible thanks to models of junction but can be tedious according to the number of parameters to fit. In the last few years, the idea of models based on a two dimensional conservation laws arose in order to represent traffic flow in large and dense networks. This study starts with a simple model [33] for homogeneous network and where a preferred direction of traffic exists. Our aim is to extend gradually this model by adding complexity. As this approach is uncommon, we investigate a way to compare the results of this model with microsimulation in [73] using Aimsun. Then, in the literature, the network is mainly assumed to be homogeneous. However, in a large-scale scenario, it is unlikely that the traffic network characteristics–such as speed limit, number of lanes, or the network geometry–remain constant throughout the network. Therefore, we introduce a first extension [59] where the fundamental diagram is space-dependent and varies with respect to the area considered. Finally, we have studied more recently a possible way to relax the assumption of a preferred direction of flow by considering several layers of density such that each layer describe a different direction of flow. In this case, the model becomes a system of conservation and is hyperbolic-elliptic which imply special caution in the choice of the numerical method.

7.4. Multisensor data fusion for navigation

7.4.1. Sensors fusion for attitude estimation

Participants: H. Fourati [Contact person], Z. Zhou, J. Wu.

Attitude estimation consists in the determination of rigid body orientation in 3D space (principally in terms of Euler angles, rotation matrix, or quaternion). As a key problem for multisensor attitude determination, Wahba's problem has been studied for almost 50 years. In [42], we present a novel linear approach to solve this problem. We name the proposed method the fast linear attitude estimator (FLAE) because it is faster than known representative algorithms. The original Wahba's problem is extracted to several 1-D equations based on quaternions. They are then investigated with pseudoinverse matrices establishing a linear solution to n-D equations, which are equivalent to the conventional Wahba's problem. To obtain the attitude quaternion in a robust manner, an eigenvalue-based solution is proposed. Symbolic solutions to the corresponding characteristic polynomial are derived, showing higher computation speed. Also, to verify the feasibility in embedded application, an experiment on the accelerometer–magnetometer combination is carried out where the algorithms are compared via C++ programming language. From other side, the integration of the Accelerometer and Magnetometer (AM) provides continuous, stable and accurate attitude information for land-vehicle navigation without magnetic distortion and external acceleration. However, magnetic disturbance and linear acceleration strongly degrade the overall system performance. As an important complement, the Global Navigation Satellite System (GNSS) produces the heading estimates, thus it can potentially benefit the AM system. Such a GNSS/AM system for attitude estimation is mathematically converted to a multi-observation vector pairs matching problem in [44]. The optimal and sub-optimal attitude determination and their time-varying recursive variants are all comprehensively investigated and discussed. The developed methods are named as the Optimal Linear Estimator of Quaternion (OLEQ), Suboptimal-OLEQ (SOLEQ) and Recursive-OLEQ (ROLEQ) for different application scenarios. The theory is established based on our previous contributions, and the multi-vector matrix multiplications are decomposed with the eigenvalue factorization. Some analytical results are proven and given, which provides the reader with a brand new viewpoint of the attitude determination and its evolution. With the derivations of the two-vector case, the n-vector case is then naturally formed. The algorithms are then implemented using the C++ programming language on the designed hardware with a GNSS module, three-axis accelerometer and three-axis magnetometer, giving an effective validation of them in real-world applications. In [39], a super fast attitude solution is obtained for consumer electronics accelerometer-magnetometer combination. The quaternion parameterizing the orientation is analytically derived from a least-square optimization that maintains very simple form. Like previously developed approaches, this algorithm does not require predetermined magnetometer reference vector. In [41], we present a novel sequential multiplicative quaternion attitude estimation method from various vector sensor outputs. The unique linear constitution of the algorithm leads to its specific name of Recursive Linear Quaternion Estimator (RLQE). The algorithm's architecture is designed to use each single pair of vector observation linearly so that the vector observations can be arbitrarily chosen and fused. The closed-form covariance of the RLQE is derived that builds up the existence of a highly reliable RLQE Kalman filter (RLQE-KF). In [65], to generate the virtual-gyro output in the case of gyroscope failures, virtual-gyro Kalman filter is established for angular rate estimation base on attitude estimation results.

7.4.2. Attitude estimation applied in augmented reality

Participants: H. Fourati [Contact person], T. Michel, P. Genevès, N. Layaïda.

We investigate the precision of attitude estimation algorithms in the particular context of pedestrian navigation with commodity smartphones and their inertial/magnetic sensors. A particular attention was paid to the study of attitude estimation in the context of augmented reality motions when using smartphones [32]. We report on an extensive comparison and experimental analysis of existing algorithms. We focus on typical motions of smartphones when carried by pedestrians. We use a precise ground truth obtained from a motion capture system. We test state-of-the-art and built-in attitude estimation techniques with several smartphones, in the presence of magnetic perturbations typically found in buildings. We discuss the obtained results, analyze advantages and limits of current technologies for attitude estimation in this context. Furthermore, we propose a new technique for limiting the impact of magnetic perturbations with any attitude estimation algorithm used in this context.

7.4.3. Attitude determination for satellite

Participants: H. Fourati [Contact person], S. Pourtakdoust, Csug Team, E. Kerstel.

Recently, we started to work on attitude estimation for satellites. In [29], we are focused on the development and verification of a heat attitude model (HAM) for satellite attitude determination. Within this context, the Sun and the Earth are considered as the main external sources of radiation that could affect the satellite surface temperature changes. Assuming that the satellite orbital position (navigational data) is known, the proposed HAM provides the satellite surface temperature with acceptable accuracy and also relates the net heat flux (NHF) of three orthogonal satellite surfaces to its attitude via the inertial to satellite transformation matrix. The proposed HAM simulation results are verified through comparison with commercial thermal analysis tools. The proposed HAM has been successfully utilized in some researches for attitude estimation, and further studies for practical implementations are still ongoing. Actually, we are establishing a project around quantum communication experiments under Nanobob CubeSat mission [28]. Some attitude estimation algorithms will be deployed to orient the satellite to the ground station.

7.4.4. Sensors fusion for distance measurement in pedestrian navigation

Participants: H. Fourati [Contact person], Z. Zhou, J. Wu.

We developed in [43] a foot-mounted pedestrian navigation system prototype with the emphasis on distance measuring with an inertial measurement unit (IMU) which implies the characteristics of pedestrian gait cycle and thus can be used as a crucial step indicator for distance calculation. An adaptive time- and frequency-domains joint distance measuring method is proposed by utilizing the means of behaviors classification. Two key issues are studied: step detection and step length determination. For the step detection part, first behavior classification along with state transition strategy is designed to identify typical pedestrian behaviors including standing still, walking, running and irregular swing. Then a four-stage step detection method is proposed to adaptively determine both step frequency and threshold in a flexible window. Based on the behavior classification results, a two-segment functional based step length model is established to adapt the walking and running behaviors.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. Control of Cyber-Social Systems (C2S2)

C2C2 is a two-year project funded by the University Grenoble Alpes, MSTIC department. Evolving from recent research on network systems, this exploratory project has the objective to concentrate on cyber-social systems, that is, complex systems with interacting social and technological components. A strong motivation for this novel research direction comes from the need for innovative tools for the management of vehicular traffic. In this application, state-of-the-art approaches concentrate on hard control actions, like traffic lights: instead, future management methods should exploit soft control actions aimed at controlling the traffic demand, that is, the aggregated behaviors of the drivers.

8.1.2. Understanding data accidents for traffic safety (DATASAFE)

DATASAFE is a two years project funded by Grenoble Data Institute, with the aim to understand from real traffic data the behavior of traffic in the moments preceding an accident. The general approach is to use novel statistical techniques in order to learn traffic characteristics that can be used to develop new traffic models. Bayesian approaches are used to (supervised) classification and (unsupervised) clustering in order to respectively predict collision occurrences and discover traffic patterns.

8.1.3. Modeling autonomous vehicles in traffic flow (MAVIT)

MAVIT is a two year project funded by the University Grenoble Alpes, MSTIC department. The goal of this project is to develop a unified micro-macro approach for traffic management, involving human and autonomous vehicles drivers by providing analytical and numerical tools for traffic modeling, estimation and control. We will work towards field operational tests, by using instrumented cars to collect data on AVs trajectory and their interaction with the traffic flow with human drivers. The proposed research provides new mathematical models, computational/software tools, and engineering solutions for the control of human controlled vehicles via intelligently controlled AVs in the traffic stream. Moreover, the control of traffic via moving actuators provides a new alternative to contemporary control technologies, such as ramp metering and variable speed limits; even when AVs comprise a tiny fraction of the total fleet, these techniques may be viable, and rapidly configurable. This research considers new types of traffic models, new control algorithms for traffic flow regulation, and new sensing and control paradigms that are enabled by a small number of controllable systems anticipated in a flow. Specifically, the research focuses on new (1) micro-macro models to model few AVs in a flow; (2) estimation techniques for AV interactions with the traffic flow; (3) developing and assessing dynamical controllers to mitigate traffic events.

8.1.4. NanoSatellite Project: Advanced modelling and Control of attitude dynamics for quantum communication (SPACE)

SPACE is a two-year project funded by the IDEX University Grenoble Alpes. It aims to launch an exploratory study to find the required minimal data we need to collect and combine for software design of Nanosatellite Attitude Determination and Control System (ADCS).

8.1.5. caPture de mOuvements humainS par cenTrales inertielles/d'attitUde et smaRtphonEs : Vers l'analyse d'anomalies neurologiques et fonctions motrices (POSTURE)

POSTURE is a one-year project funded by CDP NeuroCog. The project is focused on 1) the identification and characterization of postures and reference movements in humans using appropriate algorithms of classification (machine learning), and 2) the analysis of the effects of the number, location and orientation of the inertial sensors on the performance of the methods of identification and classification of postures and movements.

8.2. National Initiatives

8.2.1. Models of Bubbles in Online Social Networks (MOB)

MOB is a PEPS S2IH INS2I 2018 interdisciplinary project. This exploratory project focuses on the effects of online recommendation systems on social dynamics, which may entail the formation of «filter bubbles» that distort the experience of the users. The project will develop a mathematical model to demonstrate these effects and propose designs for their mitigation. The research will be conducted by a blend of tools from dynamical systems, network theory, complex systems, and control systems.

8.2.2. AgileWorld-MRSEI

AgileWorld is an ANR-MRSEI project (2018-2020), which aims at building an European network for an innovative training on road transportation systems in a connected world. The funding will help to prepare and then submit a proposal for the MSCA-ITN 2019 call.

8.3. European Initiatives

8.3.1. Collaborations in European Programs, Except FP7 & H2020

8.3.1.1. Scale-FreeBack

Type: ERC Advanced Grant

Duration: Sep. 2016 to Aug. 2021

Coordinator: C. Canudas de Wit

Inria contact: 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 (see GTL), and a microscopic traffic simulator replicating the full complexity of the Grenoble urban network.

See also: http://scale-freeback.eu

8.4. International Initiatives

8.4.1. Inria Associate Teams Not Involved in an Inria International Lab

8.4.1.1. MEMENTO

Title: ModEling autonoMous vEhicles iN Traffic flOw

International Partner:

Vanderbilt University, Nashville (United States) - Dan Work

Start year: 2018

See also: http://necs.inrialpes.fr/memento/index.html

In recent years, the strategic priorities of automotive and transportation systems focus on research, development and adoption of automation-related technologies as they emerge. As these technology developments are introduced in the traffic stream, an open question is how the mathematical models that are at the heart of transportation planning and operations will need to be advanced to accommodate these changes. The goal of the NeCS-Vanderbilt, MEMENTO, associate team is to create a multidisciplinary environment to model autonomous vehicles (AV) in human traffic flow. Specifically, our goal is to develop a unified micro-macro approach for traffic management, involving human drivers and autonomous vehicles by providing analytical and numerical tools for traffic modeling, estimation and control. We will work towards field operational tests, by using instrumented cars to collect data on AVs trajectories and their interaction with the traffic flow with human drivers.

8.4.2. Participation in Other International Programs

8.4.2.1. TICO-MED

TicoMed (Traitement du signal, Traitement numérique multidimensionnel de l'Information avec applications aux Télécommunications et au génie Biomédical) is a French-Brazilian project funded by CAPES-COFECUB for the period 2015-2018. It involves University of Nice Sophia Antipolis (I3S Laboratory), CNAM, SUP-ELEC, University of Grenoble Alpes (Gipsa-Lab), Universidade Federal do Ceara, Universidade Federal do Rio de Janeiro, and Universidade Federal do Santa Catarina as partners.

8.5. International Research Visitors

8.5.1. Visits of International Scientists

Prof. Andrea Tosin (Politecnico di Torino, Italy) visited the team in February 2018 in the frame of the Scale-FreeBack ERC project. He gave a talk on "Control strategies for road risk mitigation in kinetic traffic modeling". He exchanged ideas with Carlos Canudas De Wit, Paolo Frasca, Stephane Mollier, Maria Laura Delle Monache and Thibault Liard.

Prof. Sandro Zampieri (Univ. Padova, Italy) visited the team in February 2018 in the frame of the Scale-FreeBack ERC project, to work with Carlos Canudas De Wit and Giacomo Casadei.

Prof. Karl Henrik Johansson (KTH, Stockholm, Sweden) visited the team in March 2018 in the frame of the Scale-FreeBack ERC project, and gave a talk on "Control of vehicle platoons and their influence on traffic".

Prof. Dan Work (Vanderbilt University (USA)), visited the team in July 2018 to work with Maria Laura Delle Monache and Thibault Liard, in the framework of the associated team MEMENTO.

Mauro Franceschelli (University of Cagliari, Italy) visited the team in October 2018 to collaborate with P. Frasca.

Prof. Olga Lucia Quintero Montoya, Univ. EAFIT, Medellin, Colobmia, visited the team in September 2018. She worked with C. Canudas de Wit on the theoretical development of a normalized macroscopic fundamental diagram for urban traffic.

George Gunter and Raphael Stern (University of Illinois at Urbana-Champaign and Vanderbilt University (USA)) visited the team in November 2018 to work with Maria Laura Delle Monache and Thibault Liard, in the framework of the associated team MEMENTO.

Maolong Lyu is a PhD student from TU Delft (Netherlands) under the supervision of Prof. Simone Baldi. He visited the team for two months to work with M.L. Delle Monache and P. Frasca on string stability for microscopic traffic flow models describing mixed traffic (human drivers and autonomous vehicles).

Diego Deplano is a PhD student from Univ. Cagliari (Italy) under the supervision of Prof. Alessandro Giua. He is visiting the team since Sept. 2018, working with C. Canudas de Wit.

8.5.1.1. Internships

Alexandre Olikier, “Open multi-agent systems with fixed size and possibly not complete topologies”, December 2017–June 2018. Université catholique de Louvain, Belgium. Jointly advised by Paolo Frasca and Julien Hendrickx.

8.5.2. Visits to International Teams

8.5.2.1. Research Stays Abroad

P. Frasca is a Visiting Scientist at the IEIIT-CNR Institute, National Research Council CNR, Torino, Italy. By this collaboration, he performs research on distributed estimation in sensor networks and distributed control of social networks. He visited Torino three times in 2018.

P. Frasca is a Visiting Faculty at the Department of Applied Mathematics, University of Twente, Enschede, The Netherlands. By this collaboration, he performs research on vehicle platooning and on the dynamics of social media. He visited Enschede three times in 2018.

M. L. Delle Monache visited University of Alabama (USA) in April 2018.

M. L. Delle Monache visited Vanderbilt University (USA) in May 2018, and T. Liard visited the same university in May-June and December 2018. These visits are in the frame of the MEMENTO associate team.

F. Garin visited Rutgers University (Philadelphia, USA) in April 2018, to initiate a collaboration with Prof. Benedetto Piccoli and his students on metabolic networks.

A. Kibangou visited the University of Johannesburg (South Africa) in October 2018. During his stay, he gave a lecture to students of Department of Town and Regional Planning of Univ. of Johannesburg on Mobility and traffic management.

N. Martin visited Imura Laboratory at Tokyo University of Technology from June 20th to August 20th, in the frame of the JSPS summer program. The aim of this collaboration is to integrate controllability and/or observability notions in the network reduction problem at the core of this Ph.D. work.

M. U. B. Niazi visited Professor Jacquelien Scherpen at the University of Groningen, Netherlands, in October 2018, to work on model reduction for network systems.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. Member of the Organizing Committees

The team organized the international ERC Scale-FreeBack workshop on “Analysis and Control of Large-Scale Complex Networks”, Grenoble, September 10-11th, 2018 (http://scale-freeback.eu/workshop-on-analysis-and-control-of-large-scale-complex-networks-10-11-sept-2018-grenoble/).

M. L. Delle Monache organized a mini-symposium on “Modélisation et gestion du trafic routier”, 44e Congrès National d’Analyse Numérique, May 2018 (with P. Goatin, Acumes team).

M. L. Delle Monache organized a workshop on “Traffic flow control via PDE techniques”, CDC, December 2018 (with Nikolaos Bekiaris-Liberis, Delphine Bresch-Pietri and Rafael Vazquez).

Team members organized the following invited sessions at the European Control Conference ECC 2018, Cyprus, June 2018:

- “Model reduction and control in large-scale networks” (P. Frasca and C. Canudas de Wit)
- “Multi-agent network games” (F. Garin, with S. Grammatico from Delft Univ. of Technology)

9.1.2. Scientific Events Selection

9.1.2.1. Member of the Conference Program Committees

C. Canudas de Wit has served as Associate Editor at Large for the American Control Conference ACC 2019.

P. Frasca has served as Associate Editor in the conference editorial boards for the 7th IFAC Workshop on Distributed Estimation and Control in Networked Systems and the 23rd International Symposium on Mathematical Theory of Networks and Systems (MTNS).

F. Garin is Associate Editor in the IEEE Control System Society Conference Editorial Board (this year, she served for CDC 2018, ACC 2019) and Associate Editor in the European Control Association (EUCA) Conference Editorial Board (this year, she served for ECC 2019).

H. Fourati was member of:

- the International Program Committee (IPC) of international conferences STA'18, ICCAD'18, ICITE'18.
- the International Program Committee (IPC)/Associate Editor for contributed papers for the IEEE Conference on Control Technology and Applications (CCTA'18), Copenhagen (Denmark), Aug. 2018;
- the Technical Program Committee (TCP) for the International Conference on Indoor Positioning and Indoor Navigation (IPIN'18), Nantes (France), Sep. 2018;
- the committee of the reviewing phase of the 21st Euro Working Group on Transportation Meeting (EWGT'18), Braunschweig (Germany), Sep. 2018.

9.1.2.2. Reviewer

Team members have been reviewers for several conferences, including the most prestigious ones in their research area: IEEE Conference on Decision and Control CDC, European Control Conference ECC, American Control Conference ACC, European Signal Processing Conference, IEEE International Conference on Robotics and Automation ICRA, IEEE/RSJ International Conference on Intelligent Robots and Systems IROS, IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys), IFAC Workshop on Control for Transportartion Systems (CTS), IEEE Intelligent Transportation Systems Society Conference, Transportation Research Board Annual Meeting.

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

C. Canudas de Wit is Associate Editor of the IEEE Transactions on Control of Networks Systems IEEE-TCNS (since June 2013) and Editor of the Asian Journal of Control AJC (since 2010).

P. Frasca is Subject Editor of the International Journal of Robust and Nonlinear Control (Wiley) (since February 2014), Associate Editor of the IEEE Control System Letters (from February 2017) and Associate Editor of the Asian Journal of Control (Wiley) (since January 2017).

H. Fourati is Associate Editor of the Asian Journal of Control (Wiley) (since January 2016) and of the Open Transportation Journal https://benthamopen.com/TOTJ/editorial-board. He has also been guest editor of the special issue "Multi-sensor Integrated Navigation and Location based services applications" for International Journal of Distributed Sensor Networks (IJDSN), 2017-2018 (http://journals.sagepub.com/topic/collections-dsn/dsn-1-msinalbsa/dsn) and lead guest editor of the special issue "Recent Advances on Data Fusion, Estimation in Navigation and Control" for Asian Journal of Control (AJC), 2018.

9.1.3.2. Reviewer - Reviewing Activities

Team members have been reviewers for several journals, including the most prestigious ones in their research area: IEEE Trans. on Automatic Control, IEEE Trans. on Control of Network Systems, IEEE Trans. on Signal Processing, Automatica, IEEE Signal Processing Letters, Systems and Control Letters, Int. Journal of Robust and Nonlinear Control, Elsevier Transportation Research Part B, IEEE Trans. on Intelligent Transportation Systems, IEEE/ASME Trans. on Mechatronics, IEEE Trans. on Instrumentations and Measurements, IEEE Sensors journal, IEEE Trans. on Robotics, AIMS Networks and Heterogeneous Network (NHM), Wiley Mathematical Methods in the Applied Sciences (MMAS), Journal of Mathematical Analysis and Applications (JMMA), Journal of Nonlinear Science and Applications (JNSA), Journal of the Franklin Institute, AMS Mathematical Reviews, Asian Journal of Control.

9.1.4. Invited Talks

- C. Canudas de Wit, “Model and Control of Large scale systems", plenary talk at IFAC-NecSys’18, Groningen, The Netherlands, August 2018.
- C. Canudas de Wit, “Control of Large scale Urban networks: a new perspective", plenary talk at IFAC-CTS’18, Savona, Italy, June 2018
- C. Canudas de Wit, “Scale-FreeBack", pitch talk at Transport Research Arena, Vienna, Austria, April 2018 .
- C. Canudas de Wit, “Towards Scale-Free Control of Large-scale Traffic Networks” and M. L. Delle Monache, “Micro-macro traffic modeling for estimation and control”, First SoPhy International Workshop on Societal-Scale Cyber-Physical Transport Systems Workshop, Stockholm, Sweden, September 2018.
- M. L. Delle Monache, “Can big data help traffic flow control?”, Workshop: Traffic flow control via PDE Techniques, IEEE-CDC Conference, Miami Beach, USA, December 2018.
- M. L. Delle Monache, “Control and estimation of traffic flow using autonomous vehicles”, Joint meeting of the Italian Mathematical Union, the Italian Society of Industrial and Applied Mathematics and the Polish Mathematical Society, Wroclaw, Poland, September 2018.
- M. L. Delle Monache, “Riemann solver for a macroscopic double-lane roundabout model”, 15th IFAC Symposium on Control in Transportation Systems, Savona, Italy, June 2018.
- M. L. Delle Monache, “Control of traffic: from ramp metering to autonomous vehicles”, Institute for Software Integrated Systems, Vanderbilt University, USA, May 2018.
- M. L. Delle Monache, “Control of traffic flow: from ramp metering to autonomous vehicles”, Seminar of the department of mathematics, University of Alabama, USA, April 2018
- M. L. Delle Monache, “Two-dimensional macroscopic model for large scale traffic network”, Incontro Scientifico su Modellizzazione ed Analisi di Problemi di Folle e Traffico, Politecnico di Torino, Italy, April 2018.
- M. L. Delle Monache, “Les mathématiques cachées du trafic routier”, ISN Conference, Académie de Grenoble, Inria Grenoble – Rhône-Alpes, France, March 2018.
- P. Frasca, “The harmonic influence in social networks and its distributed computation by message passing”, IXXI, ENS Lyon, July 3, 2018
- P. Frasca, “Randomization and quantization in opinion dynamics”, IRSTEA, Clermont-Ferrand, March 14, 2018.
- F. Garin, “Input-and-state observability of structured systems”, Paths in Mathematical Systems Theory workshop, Torino (Italy), Feb. 2018.

9.1.5. Leadership within the Scientific Community

Team members participate to the following technical committees of IEEE Control Systems Society and of the International Federation of Automatic Control:

- 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-TC7.1 Automotive Control (C. Canudas de Wit);
- IFAC-TC7.4 Transportation systems (C. Canudas de Wit).

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 Sweden.

P. Frasca is member of the “Comité de Direction du GdR MACS ”, term 2019-2023.

P. Frasca reviewed project proposals for the ERC and the Italian Ministry of Scientific Research; A. Kibangou reviewed project proposals for ANR, NRF (South-African research agency), and ERC.

9.1.6. Research Administration

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 is member of two local committees at Inria Rhône-Alpes: Comité des Emplois Scientifiques (post-docs, délégations) since 2015 and Comité des Études Doctorales (PhD grants CORDI-S) since 2016.
A. Kibangou is:

- Elected member of the research department MSTIC (mathematics, information and communication sciences) of Univ. Grenoble Alpes
- Co-head of the PCS (Pervasive Computing Systems) action of Persyval-Lab
- Academic director (L2) IUT1 (GEII)
- Co-head for higher studies opportunities (Responsable poursuite d’études) (IUT1-GEII)

H. Fourati is

- Member of the Department of Electrical Engineering Council, IUT1 Grenoble, France (2018-2021)
- Member of CNU61 (Conseil national des universités, Génie informatique, Automatique et Traitement du Signal) since 2016.
- In charge of communication mission and visits to high school within the Department of Electrical Engineering, IUT1 Grenoble, France (2017-present).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master and PhD: M.L. Delle Monache, Traffic flow and crowd dynamics: modeling and computing, 18h, ED MSTII, Univ. Grenoble Alpes, France.

Master: F. Garin, Distributed Algorithms and Network Systems, 13.5h, M2, Univ. Grenoble Alpes, France.

Licence: H. Fourati, Mathématiques, 30h, L2, IUT1 (GEII1), Univ. Grenoble Alpes, France.

Licence: H. Fourati, Informatique Industrielle, 95h, L1, IUT 1 (GEII), Univ. Grenoble Alpes, France.

Licence: A. Kibangou, Automatique, 75h, L2, IUT1(GEII), Univ. Grenoble Alpes, France.

Licence: A. Kibangou, Mathématiques, 44h, L2, IUT1 (GEII), Univ. Grenoble Alpes, France.

Licence: A. Kibangou, Mathématiques, 126h, L1, IUT1 (GEII), Univ. Grenoble Alpes, France.

9.2.2. Supervision

PhD: Andrés Alberto Ladino Lopez, Traffic state estimation and prediction in freeways and urban networks, Univ. Grenoble Alpes, March 2018, co-advised by C. Canudas de Wit, A. Kibangou and H. Fourati.

PhD: Sebin Gracy, Input and state observability of linear network systems with application to security of cyber-physical systems, Univ. Grenoble Alpes, Nov. 2018, co-advised by A. Kibangou and F. Garin.

PhD: Stéphane Durand, Analysis of best response dynamics in potential games, Univ. Grenoble Alpes, Dec. 2018, co-advised by B. Gaujal and F. Garin.

PhD in progress: Stéphane Mollier, Aggregated Scale-Free Models for 2-D Large-scale Traffic Systems, from Oct. 2016, co-advised by C. Canudas de Wit, M. L. Delle Monache and B. Seibold.

PhD in progress: Nigina Toktassynova, Simulation and research of industrial flow control systems of the enterprise based on MES, from Oct. 2016, co-advised by H. Fourati and Batyrbek Suleimenov (Kazakh National Research Technical University).

PhD in progress: Nicolas Martin, On-line partitioning algorithms for evolutionary scale-free networks, from Dec. 2016, co-advised by C. Canudas de Wit and P. Frasca.

PhD in progress: Martin Rodriguez-Vega, Traffic density, traveling time and vehicle emission estimation in large-scale traffic networks, from Oct. 2017, co-advised by C. Canudas de Wit and H. Fourati.

PhD in progress: Muhammad Umar B. Niazi, State-state estimation design and optimal sensor placement algorithms for large-scale evolutionary dynamical networks, from Dec. 2017, co-advised by C. Canudas de Wit and A. Kibangou.

PhD in progress: Thembani Moyo, Origin and destination modeling and estimation for smart mobility, from May 2018, co-advised by A. Kibangou and W. Musakwa (Univ. of Johannesburg).

PhD in progress: Denis Nikitin, Scalable large-scale control of network aggregates, from Sept. 2018, co-advised by C. Canudas de Wit and P. Frasca.

PhD in progress: Liudmila Tumash, Traffic control in large-scale urban networks, from Sept. 2018, co-advised by C. Canudas de Wit and M. L. Delle Monache.

PhD in progress: Bassel Othman, Dynamic optimization of road traffic in a large-scale urban network from Oct. 2018, co-advised by C. Canudas de Wit and G. De Nunzio.

PhD in progress: Makia Zmitri, Estimating the attitude by IMU, magnetic and vision measures: an automatic control approach, from Oct. 2018, co-advised by H. Fourati and C. Prieur.

9.2.3. Juries

- P. Frasca was committee member of the PhD defence of Zhiyang Ju. Thesis: *Persistent Communication Connectivity of Multi-agent Systems*. University of Melbourne, Australia. PhD advisor: Dragan Nesic and Iman Shames. 2018
- P. Frasca was committee member of the PhD defence of Pierre-Yves Chevalier. Thesis: *Inhomogeneous Products of Stochastic Matrices with Application to Consensus Systems*. Université catholique de Louvain, Louvain-la-Neuve, Belgium. Ph.D. advisors: Julien Hendrickx and Raphael Jungers, June 2018
- P. Frasca was committee member of the PhD defence of Domenico Tangredi. Thesis: *Consensus in Heterogeneous Opinion Dynamics Networks*. University of Sannio, Benevento, Italy. Ph.D. advisor: Francesco Vasca, 2018.
- H. Fourati was committee member of the PhD defence of Fadoua Taia-Alaoui, IFSTTAR / Univ. Nantes, Dec. 2018.
- F. Garin was scientific assessor for the promotion of Maben Rabi to 'oavlönad docent', Chalmers University of Technology (Sweden), Jan. 2018.

- A. Kibangou was a reviewer of the PhD thesis of Thomas Brault "Étude des algorithmes de fusion de données pour estimer l'orientation d'un objet", Sorbonne Universités, defended November 8th, 2018.
- A. Kibangou was a reviewer of the thesis of Smart Dumba "Modelling Signalised Intersections' Capacity under the Impact of Minibus Public Transport in Harare, Zimbabwe", University of Zimbabwe. To be defended in January 2019.

9.3. Popularization

9.3.1. Articles and contents

P. Frasca has co-authored a column on the IEEE Control Systems Magazine about the activities of the Technical Committee on Networks and Communications Systems [67].

9.3.2. Education

M. L. Delle Monache gave a talk on "Les mathématiques cachées du trafic routier" to the high school teachers in the framework of the ISN Conference in collaboration with the Académie de Grenoble. The video of the conference is available at https://www.canal-u.tv/video/inria/les_mathematiques_cachees_du_trafic_routier.44275.

9.3.3. Interventions

Vadim Bertrand presented demos of the GTL-Ville:

- at *Club PTV Vision* (https://discover.ptvgroup.com/Club_PTV_Vision_2018), on Oct. 4th, in Paris
- at *Rencontres Inria-industrie* (https://www.inria.fr/innovation/recherche-partenariale-transfert/rencontres-inria-industrie/presentation), on Nov. 20th, in Paris

10. Bibliography

Major publications by the team in recent years

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[2] G. De Nunzio, C. Canudas de Wit, P. Moulin, D. Di Domenico. *Eco-Driving in Urban Traffic Networks Using Traffic Signals Information*, in "International Journal of Robust and Nonlinear Control", 2016, n^o^ 26, pp. 1307–1324 [*DOI :* 10.1002/RNC.3469], https://hal.archives-ouvertes.fr/hal-01297629

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] S. DURAND. *Analysis of best response dynamics in potential games*, Université Grenoble Alpes, December 2018

[12] S. GRACY. *Input and state observability of linear network systems with application to security of cyber-physical systems*, Université Grenoble Alpes, November 2018

[13] A. LADINO LOPEZ. *Traffic state estimation and prediction in freeways and urban networks*, Université Grenoble Alpes, March 2018, https://tel.archives-ouvertes.fr/tel-01867240

Articles in International Peer-Reviewed Journals

[14] F. ACCIANI, P. FRASCA, G. HEIJENK, A. STOORVOGEL. *Achieving robust average consensus over lossy wireless networks*, in "IEEE Transactions on Control of Network Systems", 2018, pp. 1 - 11 [*DOI :* 10.1109/TCNS.2018.2800407], https://hal.archives-ouvertes.fr/hal-01699122

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