Activity Report 2016

Project-Team MAESTRO

Models for the performance analysis and the control of networks

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Networks and Telecommunications

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Creation of the Project-Team: 2003 October 01, end of the Project-Team: 2016 December 31

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1. Members

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2. Overall Objectives

2.1. Presentation of MAESTRO

MAESTRO is an Inria project-team whose members are located in Sophia Antipolis (S. Alouf, K. Avrachenkov, G. Neglia), at LIA (Lab. of Informatics of Avignon) in Avignon (E. Altman) and at LIRMM (Lab. Informatics, Robotics and Microelectronics of Montpellier) in Montpellier (A. Jean-Marie). MAESTRO is concerned with the modeling, performance evaluation, optimization and control of stochastic Discrete-Event Dynamical Systems (DEDS), with a particular emphasis on networks and their applications. The scientific contributions are both theoretical, with the development of new modeling formalisms, and applied, with: a) the solution of specific problems arising in one of our application domains, b) the development of software tools for the performance evaluation of DEDS, and c) the patenting of new methods jointly with industrial partners.

3. Research Program

3.1. Research Directions

MAESTRO's research directions belong to five main themes motivated by direct applications: network science, wireless networks, network engineering games, green networking and smart grids, content-oriented systems. These directions are very connected: network engineering games find applications in many networking fields, from wireless protocols to applications such as social networks. Green IT studies are often concerned with wireless networks, etc. The study of these applications often raises questions of methodological nature, less close to direct applications; these advances are reported in a separate section.

3.1.1. Network Science

MAESTRO contributes to this new fast growing research subject. "Network Science" or "Complex Network Analysis" aims at understanding the structural properties and the dynamics of a variety of large-scale networks in telecommunications (e.g. the graph of autonomous systems, the Web graph), social science (e.g. community of interest, advertisement, reputation, recommendation systems), bibliometrics (e.g. citations, co-authors), biology (e.g. spread of an epidemic, protein-protein interactions), and physics. It has been observed that the complex networks encountered in these areas share common properties such as power law degree distribution, small average distances, community structure, etc. It also appears that many general questions/applications (e.g. community detection, epidemic spreading, search, anomaly detection) are common in various disciplines which study networks. In particular, we aim at understanding the evolution of complex networks with the help of game theoretical tools in connection with Network Engineering Games, as described below. We design efficient tools for measuring specific properties of large scale complex networks and their dynamics. More specifically, we work on the problem of distributed optimization in large networks where nodes cooperatively solve an optimization problem relying only on local information exchange.

3.1.2. Wireless Networks

The amazing technological advances in wireless devices has led networks to become heterogeneous and very complex. Many research groups worldwide investigate performance evaluation of wireless technologies. MAESTRO's specificity relies on the use of a large variety of analytic tools from applied probability, control theory and distributed optimization to study and improve wireless networks functionalities. We investigate in particular problems of self-organization, channel selection and power control, the association problem and others.

3.1.3. Network Engineering Games

The foundations of *Network Engineering Games* are currently being laid. These are games arising in telecommunications engineering at all the networking layers. This includes considerations from information and communications theory for dealing with the physical and link layers, along with cross layer approaches. MAESTRO's focus is on three areas: *routing games*, *evolutionary games* and *epidemic games*. In routing games we progress on the theory for costs that are not additive over links (such as packet losses or call blocking probabilities). We pursue their research in the stochastic extension of evolutionary game theory, namely the "anonymous sequential games" in which we study the total expected costs and the average cost. Within epidemic games they study epidemics that compete against each other. We apply this to social networks, considering in particular the coupling between various social networks (e.g. propagation strategies that combine Twitter, FaceBook and other social networks).

3.1.4. Green Networking and Smart Grids

The ICT (Information and Communications Technology) sector is becoming one of the main energy consumers worldwide. There is awareness that networks should have a reduced environmental footprint. Our objective is to have a systematically "green" approach when solving optimization problems. The energy cost and the environmental impact should be considered in optimization functions along with traditional performance metrics such as throughput, fairness or delay. We aim at contributing to the design and the analysis of future green networks, in particular those using renewable energy.

Researchers envision that future electricity distribution network will be "smart", with a large number of small generators (due to an extensive use of renewable energies) and of consumer devices able to adapt their energy needs to a time-varying offer. Generators and devices will be able to locally communicate through the electrical grid itself (or more traditional communication networks), in order to optimize production, transport and use of the energy. This is definitely a new application scenario for MAESTRO, to which we hope to be able to contribute with our expertise on analytic models and performance evaluation.

3.1.5. Content-Oriented Systems

We generally study problems related with the placement and the retrieval of data in communication networks.

We are particularly interested in In-network caching, a widely adopted technique to provide an efficient access to data or resources on a world-wide deployed system while ensuring scalability and availability. For instance, caches are integral components of the Domain Name System, the World Wide Web, Content Distribution Networks, or the recently proposed Information-Centric Network (ICN) architectures. We analyze network of caches, study their optimal placement in the network and optimize data placement in caches/servers.

We also study other aspects related to replication and placement of data: how much to replicate it and on which servers to place it? Finally, we study optimal ways of retrieving the data through prefetching.

3.1.6. Advances in Methodological Tools

MAESTRO has a methodological activity that aims at advancing the state of the art in the tools used for the general performance evaluation and control of systems. We contribute to such fields as perturbation analysis, Markov processes, queueing theory, control theory and game theory. Another objective is to enhance our activity on general-purpose modeling algorithms and software for controlled and uncontrolled stochastic systems.

3.2. Scientific Foundations

The main mathematical tools and formalisms used in MAESTRO include:

- theory of stochastic processes: Markov process, renewal process, branching process, point process, Palm measure, large deviations, mean-field approximation, fluid approximation;
- theory of dynamical discrete-event systems: queues, pathwise and stochastic comparisons, random matrix theory;
- theory of control and scheduling: dynamic programming, Markov decision process, game theory, deterministic and stochastic scheduling; stochastic approximation algorithms;
- theory of singular perturbations.

4. Application Domains

4.1. Main Application Domains

MAESTRO's main application area is networking, to which we apply modeling, performance evaluation, optimization and control. Our primary focus is on protocols and network architectures, and recent evolutions include the study of the Web and social networks, as well as models for Green IT.

- Wireless (cellular, ad hoc, sensor) networks: WLAN, WiMAX, UMTS, LTE, HSPA, delay tolerant networks (DTN), power control, medium access control, transmission rate control, redundancy in source coding, mobility models, coverage, routing, green base stations,
- Internet applications: social networks, content distribution systems, peer-to-peer systems, overlay networks, multimedia traffic, video-on-demand, multicast;
- Information-Centric Networking (ICN) architectures: Content-Centric Network (CCN, also called Content-Oriented Networks);
- Internet infrastructure: TCP, high speed congestion control, voice over IP, service differentiation, quality of service, web caches, proxy caches.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

The paper “Access-time Aware cache Algorithms” by Giovanni Neglia; Damiano Carra; Mingdong Feng; Vaishnav Janardhan; Pietro Michiardi and Dimitra Tsigkari got the Best Paper Award at ITC 28 in Würzburg.

The article “Sonorous Cartography for Sighted and Blind People” by Didier Josselin, Andelbery Saidi, Dorian Roussel, Said Boularouk, Olivier Bonin, Eitan Altman, Driss Matrouf got the Best Short Paper Award at the conference 19th AGILE International on Geographic Information Science, Helsinki, Finland, June 14-17, 2016.

S. Alouf has received a “Recognition of Service Award” from the ACM in September 2016.

BEST PAPERS AWARDS:

[46]
G. NEGLIA, D. CARRA, M. FENG, V. JANARDHAN, P. MICHIARDI, D. TSIGKARI. *Access-time aware cache algorithms*, in "International Teletraffic Congress ITC-28", Würzburg, Germany, Proc. of ITC-28, September 2016, https://hal.inria.fr/hal-01402425

[40]
D. JOSSELIN, D. ROUSSEL, S. BOULAROUK, A. SAIDI, D. MATROUF, O. BONIN, E. ALTMAN. *Sonorous cartography for sighted and blind people*, in "AGILE’2016 - 19th AGILE International Conference on Geographic Information Science", Helsinki, Finland, June 2016, https://hal.archives-ouvertes.fr/hal-01338081

6. New Software and Platforms

6.1. marmoteCore

Markov Modeling Tools and Environments - the Core
KEYWORDS: Modeling - Stochastic models - Markov model
FUNCTIONAL DESCRIPTION

marmoteCore is a C++ environment for modeling with Markov chains. It consists in a reduced set of high-level abstractions for constructing state spaces, transition structures and Markov chains (discrete-time and continuous-time). It provides the ability of constructing hierarchies of Markov models, from the most general to the particular, and equip each level with specifically optimized solution methods.

This software is developed within the ANR MARMOTE project: ANR-12-MONU-00019.

- Participants: Alain Jean-Marie, Issam Rabhi
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- Contact: Alain Jean-Marie
- URL: http://marmotecore.gforge.inria.fr/

6.2. ns-3

KEYWORDS: Simulation - Communication networks
FUNCTIONAL DESCRIPTION

ns-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use.

In the framework of the research project with ALSTOM Transport (see §8.1.3), we have extensively validated several modules of ns-3, related to the PHY and the MAC layers. We have implemented a directional antenna using 3-dimensional data for the radiation diagram. Modules related to the Automatic Train Protection function used in train systems have been implemented and validated. We have also developed a generator of video traffic and objects that allow to generate easily simulation scenarios.

We have made available the code related to the communication based train control and the one generating video traffic. Some of our contribution to the ns-3 simulator and selected results illustrating some of the issues that can be addressed using our contribution are presented and discussed in [35].

- Participants: Sara Alouf, Giovanni Neglia and Alina Tuholukova
- Contact: Alina Tuholukova
- ns-3 codereview issue of the cbtc module: https://codereview.appspot.com/289110043
- ns-3 codereview issue of the video generator: https://codereview.appspot.com/286160043

7. New Results

7.1. Network Science

Participants: Eitan Altman, Konstantin Avrachenkov, Arun Kadavankandy, Jithin Kazhuthuveettil Sreedharan, Hlib Mykhailenko, Giovanni Neglia, Alina Tuholukova.

7.1.1. Computation on Large Graphs

The MAESTRO team has been working on how to partition large graphs in distributed computation frameworks in order to speed up the execution time.

In [43], H. Mykhailenko and G. Neglia in collaboration with F. Huet (Univ. Côte d'Azur, CNRS, I3S), provide an overview of existing edge partitioning algorithms. However, based only on published work, it is not possible to draw a clear conclusion about the relative performances of these partitioners. For this reason, the authors compare all the edge partitioners currently available for the widely-used framework for graph processing Apache GraphX. Preliminary results suggest that the Hybrid-Cut partitioner provides the best performance.

In [44], H. Mykhailenko and G. Neglia in collaboration with F. Huet (Univ. Côte d'Azur, CNRS, I3S), focus on vertex-cut graph partitioning and they investigate how it is possible to evaluate the quality of a partition before running the computation. To this purpose the authors scrutinize a set of metrics proposed in literature. They carry experiments with Apache GraphX and they perform an accurate statistical analysis. Preliminary experimental results show that communication metrics like vertex-cut and communication cost are effective predictors on most of the cases.

7.1.2. Network centrality measures

In [19], K. Avrachenkov in collaboration with V. Mazalov (Karelian Institute of Applied Mathematical Research, Russia), L. Trukhina (Baikal State Univ. of Economics and Law, Russia) and B. Tsynguev (Transbaikal State Univ., Russia) worked on network centrality measures based on game-theoretic concepts. The betweenness centrality is one of the basic concepts in the analysis of the social networks. Initial definition for the betweenness of a node in the graph is based on the fraction of the number of geodesics (shortest paths) between any two nodes that given node lies on, to the total number of the shortest paths connecting these nodes. This method has polynomial complexity. We propose a new concept of the betweenness centrality for weighted graphs using the methods of cooperative game theory. The characteristic function is determined by special way for different coalitions (subsets of the graph). Two approaches are used to determine the characteristic function. In the first approach the characteristic function is determined via the number of direct and indirect weighted connecting paths in the coalition. In the second approach the coalition is considered as an electric network and the characteristic function is determined as a total current in this network. We use Kirchhoff's law. After that the betweenness centrality is determined as the Myerson value. The results of computer simulations for some examples of networks, in particular, for the popular social network "VKontakte", as well as the comparing with the PageRank method are presented.

7.1.3. Sampling and Inference of Complex Networks

In [32] K. Avrachenkov, G. Neglia and A. Tuholukova study chain-referral methods for sampling in social networks. These methods rely on subjects of the study recruiting other participants among their set of connections. This approach gives us the possibility to perform sampling when the other methods, that imply the knowledge of the whole network or its global characteristics, fail. Chain- referral methods can be implemented with random walks or crawling in the case of online social networks. However, the estimations made on the collected samples can have high variance, especially with small sample size. The other drawback is the potential bias due to the way the samples are collected. We suggest and analyze a subsampling technique, where some users are requested only to recruit other users but do not participate to the study. Assuming that the referral has lower cost than actual participation, this technique takes advantage of exploring a larger variety of population, thus decreasing significantly the variance of the estimator. We test the method on real social networks and on synthetic ones. As by-product, we propose a Gibbs-like method for generating synthetic networks with desired properties.

Function estimation on Online Social Networks (OSN) is an important field of study in complex network analysis. An efficient way to do function estimation on large networks is to use random walks. We can then defer to the extensive theory of Markov chains to do error analysis of these estimators. In [29], K. Avrachenkov, A. Kadavankandy and J.K. Sreedharan in collaboration with V. Borkar (IIT Bombay, India) compare two existing techniques, Metropolis-Hastings MCMC and Respondent-Driven Sampling, that use random walks to do function estimation and compare them with a new reinforcement learning based technique. We provide both theoretical and empirical analyses for the estimators we consider.

In [33] K. Avrachenkov and J.K. Sreedharan in collaboration with B. Ribeiro (Purdue Univ., USA) develop random walk based methods for inference in Online Social Networks (OSNs) to answer questions like are OSN users more likely to form friendships with those with similar attributes? Do users at an OSN A score content more favorably than OSN B users? Such questions frequently arise in the context of Social Network Analysis (SNA) but often crawling an OSN network via its Application Programming Interface (API) is the only way to gather data from a third party. To date, these partial API crawls are the majority of public datasets and the synonym of lack of statistical guarantees in incomplete-data comparisons, severely limiting SNA research progress. Using regenerative properties of the random walks, we propose estimation techniques based on short crawls that have proven statistical guarantees. Moreover, our short crawls can be implemented in massively distributed algorithms. We also provide an adaptive crawler that makes our method parameter-free, significantly improving our statistical guarantees. We then derive the Bayesian approximation of the posterior of the estimates, and in addition, obtain an estimator for the expected value of node and edge statistics in an equivalent configuration model or Chung-Lu random graph model of the given network (where nodes are connected randomly) and use it as a basis for testing null hypotheses. The theoretical results are supported with simulations on a variety of real-world networks.

In [30] K. Avrachenkov in collaboration with L. Iskhakov and M. Mironov (Moscow Institute of Physics and Technology, Russia) consider pairwise Markov random fields which have a number of important applications in statistical physics, image processing and machine learning such as Ising model and labeling problem to name a couple. Our own motivation comes from the need to produce synthetic models for social networks with attributes. First, we give conditions for rapid mixing of the associated Glauber dynamics and consider interesting particular cases. Then, for pairwise Markov random fields with submodular energy functions we construct monotone perfect simulation.

7.1.4. Distributed algorithms for complex network analysis

In [31] K. Avrachenkov and J.K. Sreedharan in collaboration with P. Jacquet (Nokia Bell Labs, France) address the problem of finding top-k eigenvalues and corresponding eigenvectors of symmetric graph matrices in networks in a distributed way. We propose a novel idea called complex power iterations in order to decompose the eigenvalues and eigenvectors at node level, analogous to time-frequency analysis in signal processing. At each node, eigenvalues correspond to the frequencies of spectral peaks and respective eigenvector components are the amplitudes at those points. Based on complex power iterations and motivated from fluid diffusion

processes in networks, we devise distributed algorithms with different orders of approximation. We also introduce a Monte Carlo technique with gossiping which substantially reduces the computational overhead. An equivalent parallel random walk algorithm is also presented. We validate the algorithms with simulations on real-world networks. Our formulation of the spectral decomposition can be easily adapted to a simple algorithm based on quantum random walks. With the advent of quantum computing, the proposed quantum algorithm will be extremely useful.

In [56] K. Avrachenkov in collaboration with V. Borkar and K. Saboo (IIT Bombay, India) propose two asynchronously distributed approaches for graph-based semi-supervised learning. The first approach is based on stochastic approximation, whereas the second approach is based on randomized Kaczmarz algorithm. In addition to the possibility of distributed implementation, both approaches can be naturally applied online to streaming data. We analyse both approaches theoretically and by experiments. It appears that there is no clear winner and we provide indications about cases of superiority for each approach.

7.1.5. Random Matrix Theory for Complex Networks

In [41] A. Kadavankandy and K. Avrachenkov in collaboration with L. Cottatellucci (Eurecom, France) describe a test statistic based on the L1-norm of the eigenvectors of a modularity matrix to detect the presence of an embedded Erdos-Renyi (ER) subgraph inside a larger ER random graph. An embedded subgraph may model a hidden community in a large network such as a social network or a computer network. We make use of the properties of the asymptotic distribution of eigenvectors of random graphs to derive the distribution of the test statistic under certain conditions on the subgraph size and edge probabilities. We show that the distributions differ sufficiently for well defined ranges of subgraph sizes and edge probabilities of the background graph and the subgraph. This method can have applications where it is sufficient to know whether there is an anomaly in a given graph without the need to infer its location. The results we derive on the distribution of the components of the eigenvector may also be useful to detect the subgraph nodes.

7.1.6. Network Growth Models

Network growth and evolution is a fundamental theme that has puzzled scientists for the past decades. A number of models have been proposed to capture important properties of real networks. In an attempt to better describe reality, more recent growth models embody local rules of attachment, however they still require a primitive to randomly select an existing network node and then some kind of global knowledge about the network (at least the set of nodes and how to reach them). In [28] G. Neglia, in collaboration with B. Amorim, D. Figueiredo and G. Iacobelli (Federal Univ. of Rio de Janeiro, Brazil), proposes a purely local network growth model that makes no use of global sampling across the nodes. The model is based on a continuously moving random walk that after s steps connects a new node to its current location, but never restarts. Through extensive simulations and theoretical arguments, they analyze the behavior of the model finding a fundamental dependency on the parity of s, where networks with either exponential or a conditional power law degree distribution can emerge. As s increases parity dependency diminishes and the model recovers the degree distribution of Barabási-Albert preferential attachment model. The proposed purely local model indicates that networks can grow to exhibit interesting properties even in the absence of any global rule, such as global node sampling.

7.1.7. Competition over popularity in online social networks

In [24] E. Altman in collaboration with A. Jain and Y. Hayel (UAPV) consider a stochastic game that describes competition through advertisement over the popularity of their content. They show that the equilibrium may or may not be unique, depending on the system's parameters. They identify structural properties of the equilibria. In particular, they show that a finite improvement property holds on the best response pure policies which implies the existence of pure equilibria. They further show that all pure equilibria are fully ordered in the performance they provide to the players and propose a procedure to obtain the best equilibrium.

7.1.8. Trend detection in social networks using Hawkes processes

In [18], J. C. Louzada Pinto and T. Chahed from Telecom SudParis in collaboration with E. Altman propose a general Hawkes-based framework to model information diffusion in social networks. The proposed

framework takes into consideration the hidden interactions between users as well as the interactions between contents and social networks, and can also accommodate dynamic social networks and various temporal effects of the diffusion, which provides a complete analysis of the hidden influences in social networks. This framework can be combined with topic modeling, for which modified collapsed Gibbs sampling and variational Bayes techniques are derived. We provide an estimation algorithm based on nonnegative tensor factorization techniques, which together with a dimensionality reduction argument are able to discover the latent community structure of the social network. We provide numerical examples from real-life networks: a Game of Thrones and a MemeTracker datasets.

7.1.9. Potential Game approach to defense against virus attacks in networks

The Susceptible-Infected-Susceptible (SIS) model is a classical epidemic model where agents alternate between a sane (susceptible) and an infected state. SIS epidemic non-zero sum games have been recently used to analyse virus protection in networks. A potential game approach was proposed for solving the game for the case of a fully connected network. In [42], F.-X. Legenvre and Y. Hayel (UAPV) in collaboration with E. Altman extend this result to an arbitrary topology by showing that the general topology game is a generalized ordinal potential game. We apply this result to study numerically some examples.

7.2. Wireless Networks

Participants: Sara Alouf, Eitan Altman, Giovanni Neglia, Alina Tuholukova.

7.2.1. Control of Delay–Tolerant Networks

In [5] E. Altman and G. Neglia, in collaboration with F. De Pellegrini (Create-Net, Italy) and D. Miorandi (U-Hopper, Italy), study optimal stochastic control of delay tolerant networks. First, the structure of optimal two-hop forwarding policies is derived. In order to be implemented, such policies require knowledge of certain global system parameters such as the number of mobiles or the rate of contacts between mobiles. But, such parameters could be unknown at system design time or may even change over time. In order to address this problem, adaptive policies are designed that combine estimation and control: based on stochastic approximation techniques, such policies are proved to achieve optimal performance in spite of lack of global information. Furthermore, the paper studies interactions that may occur in the presence of several DTNs which compete for the access to a gateway node. The latter problem is formulated as a cost-coupled stochastic game and a unique Nash equilibrium is found. Such equilibrium corresponds to the system configuration in which each DTN adopts the optimal forwarding policy determined for the single network problem.

7.2.2. Performance Evaluation of Train Moving-Block Control

In moving block systems for railway transportation a central controller periodically communicates to the train how far it can safely advance. On-board automatic protection mechanisms stop the train if no message is received during a given time window. In [45], [63] G. Neglia, S. Alouf, and A. Tuholukova in collaboration with A. Dandoush (SME Sudria, France, formerly engineer with MAESTRO) and S. Simoens, P. Dersin, J. Billion and P. Derouet (all from ALSTOM Transport) consider as reference a typical implementation of moving-block control for metro and quantify the rate of spurious Emergency Brakes (EBs), i.e. of train stops due to communication losses and not to an actual risk of collision. Such unexpected EBs can happen at any point on the track and are a major service disturbance.

The general formula for the EB rate found in [45] requires a probabilistic characterization of losses and delays. Calculations are surprisingly simple in the case of homogeneous and independent packet losses. More complex loss scenarios are studied in [59]. The approach is computationally efficient even when emergency brakes are very rare (as they should be) and can no longer be estimated via discrete-event simulations.

The analytical models have also been validated using ns-3 simulations [35].

7.2.3. Speed estimation

After several years of cooperation with Nokia (formerly Alcatel-Lucent) Bell Labs in developing tools for speed estimation from measurement of the radio channel, we have now started to publish our joint patented work. This includes the work on mobility state estimation in LTE by D.-G. Herculea, V. Capdevielle, C. S. Chen, N. Ben Rached and F. Ratovelomanana from Nokia-Bell Labs in collaboration with E. Altman and M. Haddad (UAPV), see [38].

7.2.4. Sonorous cartography for sighted and blind people

E. Altman has been invited by D. Josselin from UMR Espace in UAPV to co-advise a Master project and later a thesis financed by the CNRS on Sonorous cartography. Other persons with whom we collaborate are D. Roussel, S. Boularouk, A. Saidi, M. Driss (from UAPV) and O. Bonin (Laboratoire Ville, Mobilité, Transport) all coauthors of [40] which won the best short paper award in the AGILE conference. In this article, we test the usability of a cartographic tool mixing maps and sounds. This tool is developed within QuantumGIS as a plugin prototype. We first present some theoretical reflections about synesthesia. Secondly, we explain the way we "sonificate" the images, by associating colors and recorded chords and sounds. Then we present the results of several usability tests in France with different users, including blind people.

To help blind people compensate visual perception and to better understand their outdoor environment, S. Boularouk and D. Josselin from UAPV in collaboration with E. Altman, proposed in [49] a method using human-computer interaction via Text-to-Speach. It helps visually impaired people to know surrounding places from OpenStreetMap data by hearing. The principal idea is to convey spatial information by voice synthesis and receive requests from blind people by voice recognition.

7.2.5. Scheduling for mobile users with non-stationary mobility

H. Zaaraoui and Z. Altman from Orange Labs in collaboration with T. Jiménez (UAPV) and E. Altman have studied scheduling in an environment with non-stationary mobility (cars are moving on a road and may have to stop at red lights). They propose scheduling schemes for such mobility patterns and study their performance in in [55] and in [48].

7.2.6. User Association in Multi-user MIMO Small Cell Networks

Dense Networks and large MIMO are two key enablers to achieve high data rates towards next generation 5G networks. In this context, S. Ramanath (Lekha Wireless Solutions and IIT Mumbai) and M. Debbah (Huawei) in collaboration with E. Altman study in [47] user association in an interference limited Multiuser MIMO Small Cell Network. Extending on previous findings, they derive explicit expressions for the optimal ratio of the number of antennas at the base station to the number of users that can associate to a base station in such a Network. The expressions are used to compute the actual number of users that can associate for a given interference level and other system parameters. Simulation results and numerical examples are provided to support our theoretical findings.

7.3. Network Engineering Games

Participants: Eitan Altman, Konstantin Avrachenkov, Giovanni Neglia, Nessrine Trabelsi.

7.3.1. Network formation games

Network formation games have been proposed as a tool to explain the topological characteristics of existing networks. They assume that each node is an autonomous decision-maker, ignoring that in many cases different nodes are under the control of the same authority (e.g. an Autonomous System) and then they operate as a team. In [11] K. Avrachenkov and G. Neglia in collaboration with V.V. Singh (LRI, Univ. Paris-Sud, France) introduce the concept of network formation games for teams of nodes and show how very different network structures can arise also for some simple games studied in the literature. Beside extending the usual definition of pairwise stable networks to this new setting, we define a more general concept of stability toward deviations from a specific set C of teams' coalitions (C-stability). We study then a trembling-hand dynamics, where at

each time a coalition of teams can create or sever links in order to reduce its cost, but it can also take wrong decisions with some small probability. We show that this stochastic dynamics selects C-stable networks or networks from closed cycles in the long run as the error probability vanishes.

7.3.2. Routing Games

A central question in routing games has been to establish conditions for uniqueness of the equilibrium, in terms of network topology or of costs. This question is well understood in two classes of routing games. In [27], E. Altman and C. Touati (Inria Grenoble - Rhône-Alpes) study two other frameworks of routing games in which each of several players has an integer number of connections (which are population of packets) to route and where there is a constraint that a connection cannot be split. Through a particular game with a simple three link topology, we identify various novel and surprising properties of games within these frameworks. We show in particular that equilibria are non unique even in the potential game setting of Rosenthal with strictly convex link costs.

7.3.3. Game theory applied to the Internet and social networks

In [25] E. Altman, A. Jain (UAPV) and C. Touati (Inria Grenoble - Rhône-Alpes) in collaboration with N. Shimkin (Technion), present an overview of the use of dynamic games for analyzing competition in the Internet and in on-line social networks. A special emphasis is put on identifying phenomena and tools that are novel with respet to game theory applied to other types of networks.

7.3.4. Resilience of Routing in Parallel Link Networks

E. Altman, C. Touati and A. Singhal (Inria Grenoble - Rhône-Alpes), in collaboration with J. Li (Tsukuba Univ. Japan), use a game approach in [26] to study the resilience problem of routing traffic in a parallel link network with a malicious player. They consider two players: the first wishes to split its traffic so as to minimize its average delay, which the second player, i.e., the malicious player, tries to maximize. The first player has a demand constraint on the total traffic it routes. The second player controls the link capacities: it can decrease by some amount the capacity of each link under a constraint on the sum of capacity degradation. We first show that the average delay function is convex both in traffic and in capacity degradation over the parallel links and thus does not have a saddle point. We identify best responses strategies of each player and compute both the max-min and the min-max values of the game. We provide stable algorithms for computing both max-min and min-max strategies as well as for best responses.

7.3.5. A game theoretic solution for Resource Allocation in LTE Cellular Networks

Due to Orthogonal Frequency Division Multiple Access (OFDMA) mechanism adopted in LTE cellular networks, intra-cell interference is nearly absent. Yet, as these networks are designed for a frequency reuse factor of 1 to maximize the utilization of the licensed bandwidth, inter-cell interference coordination remains an important challenge. In both homogeneous and heterogeneous cellular networks, there is a need for scheduling coordination techniques to efficiently distribute the resources and mitigate inter-cell interference. In [54], N. Trabelsi and E. Altman in collaboration with C. S. Chen, L. Roullet from Nokia Bell Labs and with R. El-Azouzi from UAPV propose a dynamic solution of inter-cell interference coordination performing an optimization of frequency sub-band reuse and transmission power in order to maximize the overall network utility. The proposed framework, based on game theory, permits to dynamically define frequency and transmission power patterns for each cell in the coordinated cluster.

7.4. Green Networking and Smart Grids

Participants: Sara Alouf, Eitan Altman, Alain Jean-Marie, Giovanni Neglia, Dimitra Politaki.

7.4.1. Power Demand Control

Demand-Response (DR) programs, whereby users of an electricity network are encouraged by economic incentives to rearrange their consumption in order to reduce production costs, are envisioned to be a key feature of the smart grid paradigm. Several recent works proposed DR mechanisms and used analytical models to derive optimal incentives. Most of these works, however, rely on a macroscopic description of the population that does not model individual choices of users. In [34], [57] G. Neglia and A. Benegiamo (PhD student in MAESTRO at the submission time), in collaboration with P. Loiseau, conduct a detailed analysis of those models and argue that the macroscopic descriptions hide important assumptions that can jeopardize the mechanisms' implementation (such as the ability to make personalized offers and to perfectly estimate the demand that is moved from a timeslot to another). Then, they start from a microscopic description that explicitly models each user's decision. They introduce four DR mechanisms with various assumptions on the provider's capabilities. Contrarily to previous studies, they find that the optimization problems that result from these mechanisms are not convex. Local optimizers can be found numerically through a heuristic. The authors present numerical simulations that compare the different mechanisms and their sensitivity to forecast errors. At a high level, their results show that the performance of DR mechanisms under reasonable assumptions on the provider's capabilities are significantly lower than those suggested by previous studies, but that the gap reduces when the population's flexibility increases.

In [22] A. Jean-Marie and G. Neglia in collaboration with I. Tinnirello, L. Giarré, M. Ippolito (Univ. of Palermo, Italy) and G. Di Bella (Telecom Italia, Italy) investigate a realistic and low-cost deployment of large scale direct control of inelastic home appliances whose energy demand cannot be shaped, but simply deferred. The idea is to exploit 1) some simple actuators to be placed on the electric plugs for connecting or disconnecting appliances with heterogeneous control interfaces, including non-smart appliances, and 2) the Internet connections of customers for transporting the activation requests from the actuators to a centralized controller. The solution requires no interaction with home users: in particular, it does not require them to express their energy demand in advance. A queuing theory model is derived to quantify how many users should adopt this solution in order to control a significant aggregated power load without significantly impairing their quality of service.

7.4.2. Geographical Load Balancing across Green Datacenters

"Geographic Load Balancing" is a strategy for reducing the energy cost of data centers spreading across different terrestrial locations. In [20] G. Neglia, in collaboration with M. Sereno (Univ. of Torino, Italy) and G. Bianchi (Univ. of Roma "Tor Vergata", Italy), focuses on load balancing among micro-datacenters powered by renewable energy sources. They model via a Markov Chain the problem of scheduling jobs by prioritizing datacenters where renewable energy is currently available. Not finding a convenient closed form solution for the resulting chain, they use mean field techniques to derive an asymptotic approximate model which instead is shown to have an extremely simple and intuitive steady state solution. After proving, using both theoretical and discrete event simulation results, that the system performance converges to the asymptotic model for an increasing number of datacenters, they exploit the simple closed form model's solution to investigate relationships and trade-offs among the various system parameters.

7.4.3. Stochastic models for solar energy

The recent popularization of renewable energy sources makes it urgent to have realistic and practical models for the renewable energy harvested by photovoltaic panels for instance. Solar radiation is intrinsically stochastic and exhibits fluctuations at several time scales. Due to the sun's position during the day with respect to a given point on Earth, there is a periodic day-night pattern that is observed on top of which short-time burstiness occurs due to fluctuating weather conditions. In [64], D. Politaki and S. Alouf propose a stochastic model for the global solar radiation. They introduce a multiplicative factor that is the ratio between the actual global solar radiation and the idealized clear sky global radiation. The latter is obtained using known astronomical models and captures the day-night pattern of the solar radiation at any given point on Earth. On the other hand, the multiplicative factor captures the short-time burstiness caused by cloudiness. A semi-

Markov model is proposed for the latter such that most of the time correlation found in measured data can be reproduced in synthetic traces.

7.5. Content-Oriented Systems

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Philippe Nain, Giovanni Neglia, Dimitra Tsigkari.

7.5.1. Modeling modern DNS caches

In-network caching is a widely adopted technique to provide an efficient access to data or resources on a world-wide deployed system while ensuring scalability and availability. In previous years, S. Alouf and N. Choungmo Fofack (former PhD student at MAESTRO, currently at Ingima) have focused on hierarchical systems that rely on expiration-based policies to manage their caches. Each cache in the system maintains for each item a timer that indicates its duration of validity. The Domain Name System (DNS) is a valid application case. The objective was to assess the performance of a polytree of caches. This work has now been published in [4].

7.5.2. Caching policies

In [46], [60], G. Neglia and D. Tsigkari, in collaboration with D. Carra (Univ. of Verona), M. Feng (Akamai Technologies), V. Janardhan (Akamai Technologies) and P. Michiardi (Eurecom), present a new cache replacement policy that takes advantage of a hierarchical caching architecture, and, in particular, of access-time difference between memory and hard disk. They prove that the proposed policy is optimal when requests follow the independent reference model, and significantly reduces the hard-disk load, as they show through their realistic trace-driven evaluation.

7.5.3. Analyzing Caching and Shaping Timeline Networks

Cache networks are one of the building blocks of information centric networks (ICNs). Most of the recent work on cache networks has focused on networks of request driven caches, which are populated based on users requests for content generated by publishers. However, user generated content still poses the most pressing challenges. For such content timelines are the de facto sharing solution. In [53], A. Reiffers-Masson (PhD student in MAESTRO at the time of submission) and E. Altman in collaboration with E. Hargreaves, W. Caarls and D. Sadoc Menasché from UFRJ (Brazil) establish a connection between timelines and publisher-driven caches. We propose simple models and metrics to analyze publisher-driven caches, allowing for variable-sized objects. Then, we design two efficient algorithms for timeline workload shaping, leveraging admission and price control in order, for instance, to aid service providers to attain prescribed service level agreements.

7.5.4. Cooperative view on Caching

The non-cooperative nature of relations between economic actors in todays networks may lead to inefficiencies and may not provide incentives for investing in deploying new technologies. In [36] E. Altman in cooperation with V. Douros and S. Elayoubi (Orange Labs) in collaboration with Y. Hayel (UAPV) have studied the question of how to split costs for deploying caches between Content Providers and Internet Service Providers. They have designed the cost sharing by casting the problem into a coalition game which they solved using the Shapely value concept.

7.5.5. Streaming optimization

The Quality of Experience (QoE) of streaming service is often degraded by frequent play-back interruptions. To mitigate the interruptions, the media player prefetches streaming contents before starting playback, at a cost of initial delay. In [23], Y. Yu and Y. Yu from Fudan Univ. in collaboration with S. Elayoubi (Orange Labs) R. El-Azouzi (UAPV) and E. Altman, study the QoE of streaming from the perspective of flow dynamics. Firstly, a framework is developed for QoE when streaming users join the network randomly and leave after downloading completion. We model the distribution of prefetching delay using partial differential equations (PDEs), and the probability generating function of playout buffer starvations using ordinary differential equations (ODEs) for constant bit-rate (CBR) streaming. Explicit form starvation probabilities and mean

start-up delay are obtained. Secondly, we extend our framework to characterize the throughput variation caused by opportunistic scheduling at the base station, and the playback variation of variable bit-rate (VBR) streaming. Our study reveals that the flow dynamics is the fundamental reason of playback starvation. The QoE of streaming service is dominated by the first moments such as the average throughput of opportunistic scheduling and the mean playback rate. While the variances of throughput and playback rate have very limited impact on starvation behavior in practice.

7.6. Advances in Methodological Tools

Participants: Eitan Altman, Konstantin Avrachenkov, Alain Jean-Marie.

7.6.1. Control theory

Linear programming formulations for the discounted and long-run average Markov Decision Processes have evolved along separate trajectories. In 2006, E. Altman conjectured that the linear programming formulations of these two models are, most likely, a manifestation of general properties of singularly perturbed linear programs. In [8] K. Avrachenkov in collaboration with J. Filar and A. Stillman (Flinders Univ., Australia) and V. Gaitsgory (Macquarie Univ., Australia) demonstrate that this is, indeed, the case.

A. Jean-Marie, together with E. Hyon (Univ. Paris-Ouest Nanterre La Défense), completed the analysis of optimal admission control in a single-server queue with impatience. In the presence of a server startup cost, linear holding costs for the queue and individual costs for departures due to impatience, the optimal policy is to either serve customers whenever some are present, or never serve any customer. The situation is decided by a simple criterion comparing the cost of starting the server to a combination of the other parameters. Proving the optimality of such a simple policy is more difficult than expected, and involves the propagation of properties through the dynamic programming operator of a suitably approximated sequence of problems, following methods and results of Blok, Bhulai and Spieksma.

7.6.2. Game theory

7.6.2.1. Uniqueness of equilibrium

E. Altman in cooperation with M. Kumar (IIT Mumbai) and R. Sundaresan (IICs) have derived in [6] a new sufficient condition for uniqueness of equilibrium which extends the Diagonal Strict Concavity condition of Rosen. They further apply the condition to various networking examples.

7.6.2.2. Hybrid games

In collaboration with V. Gaitsgory, I. Brunetti (former member of MAESTRO) and E. Altman have studied in [15] a non-zero sum game in which there are two components of the state space: one is a finite (controlled) Markov chain and the other is a vector of real numbers. Only the Markov chain is controlled; the other part of the state space evolves according to some differential equations whose parameters are the state and actions of the Markov chain. The authors have shown the existence of an asymptotic stationary equilibrium. They show how to derive epsilon equilibria policies for the original problem based on policies that are asymptotically equilibria.

7.6.2.3. Finite games

In [13] K. Avrachenkov in collaboration with V.V. Singh (LRI, Univ. Paris-Sud 11, France) consider coalition formation among players in an n-player finite strategic game over infinite horizon. At each time a randomly formed coalition makes a joint deviation from a current action profile such that at new action profile all the players from the coalition are strictly benefited. Such deviations define a coalitional better-response (CBR) dynamics that is in general stochastic. The CBR dynamics either converges to a K-stable equilibrium or becomes stuck in a closed cycle. We also assume that at each time a selected coalition makes mistake in deviation with small probability that add mutations (perturbations) into CBR dynamics. We prove that all K-stable equilibria and all action profiles from closed cycles, that have minimum stochastic potential, are stochastically stable. Similar statement holds for strict K-stable equilibria. We apply the CBR dynamics to study the dynamic formation of the networks in the presence of mutations. Under the CBR dynamics all strongly stable networks and closed cycles of networks are stochastically stable.

7.6.2.4. Dynamic Games

In a collaboration with M. Tidball (INRA, France), A. Jean-Marie considered the extension of an infinite-horizon dynamic game of groundwater extension [51], due to Provencher and Burt. As usual in this kind of models, the marginal extraction cost depends on the level of the groundwater. The goal of this paper is to point out the importance of the moment where this cost is announced to the players. We consider the case where the cost is announced before the extraction is made and the case where is announced after extractions. For both cases, we also analyse the possibility of taking into account the rainfall or not. The current literature considers only the case where the cost is announced before rain and harvesting. We characterize the equilibrium in the linear-quadratic case. We compare solutions as functions of the discount factor, with the particular cases of zero discount (myopic model) and no discount (maximization of the steady state) from the economic and the environmental points of view. We show that when the level of the groundwater is small, announcing costs after harvesting and rainfall is better from the economic and environmental point of view than the case of announcing it before harvesting and rainfall.

7.6.3. Queueing Theory

7.6.3.1. Retrial queues

In [10] K. Avrachenkov in collaboration with E. Morozov (Karelian Institute of Applied Mathematical Research, Russia) and B. Steyaert (Gent Univ., Belgium) study multi-class retrial queueing systems with Poisson inputs, general service times, and an arbitrary numbers of servers and waiting places. A class-i blocked customer joins orbit i and waits in the orbit for retrial. Orbit i works like a single-server $\cdot/M/1$ queueing system with exponential retrial time regardless of the orbit size. Such retrial systems are referred to as retrial systems with constant retrial rate. Our model is motivated by several telecommunication applications, such as wireless multi-access systems, optical networks and transmission control protocols, but represents independent theoretical interest as well. Using a regenerative approach, we provide sufficient stability conditions which have a clear probabilistic interpretation. We show that the provided sufficient conditions are in fact also necessary, in the case of a single-server system without waiting space and in the case of symmetric classes. We also discuss a very interesting case, when one orbit is unstable, whereas the rest of the system is stable.

In [9] K. Avrachenkov in collaboration with E. Morozov, R. Nekrasova (Karelian Institute of Applied Mathematical Research, Russia), and B. Steyaert (Gent Univ., Belgium) study the stability of a single-server retrial queueing system with constant retrial rate, general input and service processes. First, we present a review of some relevant recent results related to the stability criteria of similar systems. Sufficient stability conditions were obtained by (Avrachenkov and Morozov, 2014), which hold for a rather general retrial system. However, only in case of Poisson input an explicit expression is provided; otherwise one has to rely on simulation. On the other hand, the stability criteria derived by (Lillo, 1996) can be easily computed, but only hold for the case of exponential service times. We present new sufficient stability conditions, which are less tight than the ones obtained by (Avrachenkov and Morozov, 2010), but have an analytical expression under rather general assumptions. A key assumption is that interarrival times belongs to the class of *new better than used* (NBU) distributions. We illustrate the accuracy of the condition based on this assumption (in comparison with known conditions when possible) for a number of non-exponential distributions.

7.6.3.2. Polling Systems

In [12] K. Avrachenkov in collaboration with E. Perel and U. Yechiali (Tel Aviv Univ., Israel) consider a system of two separate finite-buffer $M/M/1$ queues served by a single server, where the switching mechanism between the queues is threshold-based, determined by the queue which is not being served. Applications may be found in data centers, smart traffic-light control and human behavior. We analyse both work-conserving and non-work-conserving policies. We present occasions where the non-work-conserving policy is more economical than the work-conserving policy when high switching costs are involved. An intrinsic feature of the process is an oscillation phenomenon: when the occupancy of one queue decreases, the occupancy of the other queue increases. This fact is illustrated and discussed. By formulating the system as a three-dimensional continuous-time Markov chain we provide a probabilistic analysis of the system and investigate the effects of buffer sizes and arrival rates, as well as service rates, on the system's performance. Numerical examples are presented and extreme cases are investigated.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

MAESTRO members are involved in the

- Inria Nokia Bell Labs joint laboratory: the joint laboratory consists of six ADRs (Action de Recherche/Research Action) in its second phase (starting October 2012). MAESTRO members participate in two ADRs (see §8.1.1 and §8.1.2).
- Inria ALSTOM joint laboratory: the joint laboratory consists of four projects. MAESTRO members participate in project P11 (see §8.1.3).

8.1.1. ADR "Self-Organized Networks in Wireless" (July 2008 – September 2016)

Participant: Eitan Altman.

- Contractor: Nokia Bell Labs (http://www.bell-labs.com)
- Collaborator: Laurent Roullet (coordinator).

Coordinator for Inria: Eric Fleury (team DANTE).

8.1.2. ADR "Network Science" (June 2013 – March 2017)

Participants: Konstantin Avrachenkov [coordinator], Guillaume Huard, Jithin Kazhuthuveettil Sreedharan, Giovanni Neglia.

- Contractor: Nokia Bell Labs (http://www.bell-labs.com)
- Collaborators: Philippe Jacquet (coordinator), Alonso Silva.

"Network Science" aims at understanding the structural properties and the dynamics of various kind of large scale, possibly dynamic, networks in telecommunication (e.g., the Internet, the web graph, peer-to-peer networks), social science (e.g., community of interest, advertisement, recommendation systems), bibliometrics (e.g., citations, co-authors), biology (e.g., spread of an epidemic, protein-protein interactions), and physics. The complex networks encountered in these areas share common properties such as power law degree distribution, small average distances, community structure, etc. Many general questions/applications (e.g., community detection, epidemic spreading, search, anomaly detection) are common in various disciplines and are being analyzed in this ADR "Network Science". In particular, in the framework of this ADR we are interested in efficient network sampling.

8.1.3. Project P11 "Data Communication Network Performance" (December 2013 – May 2016)

Participants: Sara Alouf [coordinator], Konstantin Avrachenkov, Philippe Nain, Giovanni Neglia, Alina Tuholukova.

- Contractor: ALSTOM Transport (http://www.alstom.com/transport/)
- Collaborators: Pierre Cotelle, Pascal Derouet (coordinator from November 2015), Pierre Dersin, Sébastien Simoens (coordinator until October 2015).

The objective of this study is to build a simulation platform (see §6.2) and develop an evaluation methodology for predicting Quality of Service and availability of the various applications supported by the data communication system of train networks.

8.1.4. "Hybrid GPS-free Localization Algorithms" (May 2016 – October 2016)

Participants: Giovanni Neglia [coordinator], Dimitra Politaki.

- Contractor: LUCIE LABS (http://www.lucielabs.com/)
- Collaborators: François Mazard.

G. Neglia and D. Tsigkari, together with F. Mazard (LUCIE LABS) did a literature survey of localization algorithms that could be deployed in Lucie Labs entertainment wristbands. They proposed a localization algorithm that combines information from Bluetooth and WiFi connectivity in a centralized way. This activity was partially funded by AMIES (Agence pour les Mathématiques en Interaction avec l'Entreprise et la Société).

8.2. Bilateral Grants with Industry

8.2.1. Huawei CIFRE on the topic "Scalable Online Algorithms for SDN controllers" (June 2016 – May 2019)

Participants: Zaid Allybokus, Konstantin Avrachenkov.

- Contractor: Huawei Technologies (http://www.huawei.com/en/about-huawei/research-development)
- Collaborators: Jérémie Leguay et Lorenzo Maggi

Software-Defined Networking (SDN) technologies have radically transformed network architectures. They provide programmable data planes that can be configured from a remote controller platform.

The objective of this CIFRE thesis is to provide fundamental answers on how powerful SDN controller platforms could solve large online flow problems to optimize networks in real-time and in a distributed or semi-distributed fashion. We plan to use methods from both optimization and dynamic programming.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR Marmote

Participants: Alain Jean-Marie, Issam Rabhi.

ANR Program: Modèles Numériques (MN) 2012, number ANR-12-MONU-0019

Project title: MARkovian MOdeling Tools and Environments

Duration: January 2013 - June 2017

Coordinator: Alain Jean Marie (Inria)

Partners: Inria (project-teams DYOGENE, MAESTRO and MESCAL), Univ. Versailles-Saint-Quentin (DAVID lab.), Telecom SudParis (SAMOVAR lab.), Univ. Paris-Est Créteil (LACL), and Univ. Pierre-et-Marie-Curie (LIP6)

Abstract: ANR MARMOTE aims, among other goals, at realizing the prototype of a software environment dedicated to modeling with Markov chains. It brings together seven partner teams, expert in Markovian analysis, who will develop advanced solution algorithms and applications in different scientific domains: reliability, distributed systems, biology, physics and economics.

https://wiki.inria.fr/MARMOTE/Welcome

9.2. European Initiatives

9.2.1. Collaborations in European Programs, Except FP7 & H2020

Participant: Konstantin Avrachenkov.

Program: EU COST

Project acronym: ACROSS

Project title: Autonomous Control for a Reliable Internet of Services

Duration: November 2013 - November 2017

Coordinator: Rob Van Der Mei (CWI) and J.L. Van Den Berg (TNO), The Netherlands

Other partners: see http://www.cost-across.nl/

Abstract: Currently, we are witnessing a paradigm shift from the traditional information-oriented Internet into an Internet of Services (IoS). This transition opens up virtually unbounded possibilities for creating and deploying new services. Eventually, the ICT landscape will migrate into a global system where new services are essentially large-scale service chains, combining and integrating the functionality of (possibly huge) numbers of other services offered by third parties, including cloud services. At the same time, as our modern society is becoming more and more dependent on ICT, these developments raise the need for effective means to ensure quality and reliability of the services running in such a complex environment. Motivated by this, the aim of this Action is to create a European network of experts, from both academia and industry, aiming at the development of autonomous control methods and algorithms for a reliable and quality-aware IoS.

Program: EU COST

Project acronym: COSTNET

Project title: European Cooperation for Statistics of Network Data Science

Duration: May 2016 - April 2020

Coordinator: Ernst Wit (NL), Gesine Reinert (UK)

Other partners: see http://www.cost.eu/COST_Actions/ca/CA15109

Abstract: A major challenge in many modern economic, epidemiological, ecological and biological questions is to understand the randomness in the network structure of the entities they study: for example, the SARS epidemic showed how preventing epidemics relies on a keen understanding of random interactions in social networks, whereas progress in curing complex diseases is aided by a robust data-driven network approach to biology.

Although analysis of data on networks goes back to at least the 1930s, the importance of statistical network modelling for many areas of substantial science has only been recognized in the past decade. The USA is at the forefront of institutionalizing this field of science through various interdisciplinary projects and networks. Also in Europe there are excellent statistical network scientists, but until now cross-disciplinary collaboration has been slow.

This Action aims to facilitate interaction and collaboration between diverse groups of statistical network modellers, establishing a large and vibrant interconnected and inclusive community of network scientists. The aim of this interdisciplinary Action is two-fold. On the scientific level, the aim is to critically assess commonalities and opportunities for cross-fertilization of statistical network models in various applications, with a particular attention to scalability in the face of Big Data. On a meta-level, the aim is to create a broad community which includes researchers across the whole of Europe and at every stage in their scientific career and to facilitate contact with stakeholders.

9.3. International Initiatives

9.3.1. Inria Associate Teams Not Involved in an Inria International Labs

9.3.1.1. THANES

Participants: Eitan Altman, Konstantin Avrachenkov, Jithin Kazhuthuveettil Sreedharan, Philippe Nain, Giovanni Neglia.

Title: THeory and Application of NEtwork Science

International Partners (Institution - Laboratory - Researcher):

CMU (Brazil) - Department of Computer Science - Bruno Ribeiro

UFRJ (Brazil) - Department of Computer and Systems Engineering - Edmundo de Souza e Silva, Daniel Ratton Figueiredo, Daniel Sadoc

Duration: 2014 – 2017

See also: https://team.inria.fr/thanes/

Our goal is to study how services in Online Social Networks (OSN) can be efficiently designed and managed. This research requires to answer 3 main questions: 1) How can the topology of an OSN be discovered? Many services need or can take advantage of some knowledge of the network structure that is usually not globally available and in any case changes continuously due to structural dynamics. 2) How does services' adoption spread across the OSN? On the one hand the popularity of a service is determined by word-of-mouth through the links of the OSN and, on the other end, the service may contribute to reshape the structure of the OSN (e.g. by creating new connections). 3) How do different services compete for the finite attention and money of OSN users? In particular our purpose is to provide analytical models (corroborated by simulations and experiments on real networks) to understand such complex interactions.

9.3.2. Inria International Partners

9.3.2.1. Informal International Partners

MAESTRO has continued collaborations with researchers from GERAD, Univ. Montreal (Canada), Flinders Univ. (Australia), National Univ. of Rosario (Argentina), Technion - Israel Institute of Technology (Israel), Univ. of Arizona (USA), Univ. of Illinois at Urbana-Champaign (USA), Univ. of Liverpool (UK), Univ. of Massachusetts at Amherst (USA), Univ. of Florence (Italy), Univ. of Palermo (Italy), Univ. of Twente (The Netherlands) and Petrozavodsk State Univ. (Russia); Ghent Univ. (Belgium); see Sections 9.4.1.1 and 9.4.2.1.

9.3.3. Participation in Other International Programs

MAESTRO has continued collaborations with researchers from IIT Mumbai and IISc Bangalore. In 2015, these collaborations where partly supported by IFCAM and Cefipra.

9.3.3.1. International Initiatives

DyGaMe

Title: Dynamic Games Methods: theory, algorithmics and application

International Partners (Institution - Laboratory - Researcher):

Univ. de Chile (Chile) - Department of Industrial Engineering - Fernando Ordóñez

Univ. Nacional de Rosario (Argentina) - Facultad de Ciencias Exactas, Ingeniería y Agrimensura - Eugenio Della Vecchia

CNRS (France) - LIP6 - Emmanuel Hyon

Duration: 2016 - 2017

Start year: 2016

See also: https://project.inria.fr/dygame

Stochastic Dynamic Game Theory is developing in Engineering sciences and is in need of more theoretical results, algorithms and applications. This project brings together researchers from Applied Mathematics, Operations Research and Economics, with the objective of contributing to these aspects. It will more specifically concentrate on agent rationality and the game structure, look for efficient solution algorithms by crossing Applied Mathematics and Operations Research techniques, and apply the results to problems originating from, on the one hand, security/conservation concerns, and on the other hand, sustainable development problems.

CEFIPRA Grant Monte Carlo, no.5100-IT1

Title: Monte Carlo and Learning Schemes for Network Analytics

International Partners (Institution - Laboratory - Researcher):

IIT Bombay (India) - Department of Electrical Engineering - Prof. V.S. Borkar;

IIS Bangalore (India) - Department of Electrical Engineering - Prof. R. Sundaresan.

Duration: 2014 - 2017

Start year: 2014

The project aims to approach various computation problems in network analytics by means of Markov Chain Monte Carlo (MCMC) and related simulation techniques as well as machine learning algorithms such as reinforcement learning, ant colony optimization, etc. This will include network diagnostics such as ranking, centrality measures, computation on networks using local message passing algorithms, resource allocation issues pertaining to networks and network-based systems such as the internet, peer-to-peer networks, social networks. The work will involve both development of analytical tools and extensive validation thereof using simulation studies. The research will draw upon techniques from graph theory, probability, optimization, and distributed computation.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

9.4.1.1. Professors / Researchers

Bernardo Amorim

Date: 4-8 April 2016

Institution: Federal Univ. of Rio de Janeiro (Brazil)

Vivek Borkar

Date: 26-29 May and 4-17 September 2016

Institution: IIT Mumbai (India)

Damiano Carra

Date: 22-27 February and 18-22 July 2016

Institution: Univ. of Verona (Italy)

Francesco De Pellegrini

Date: 19-22 December 2016

Institution: CREATE-NET (Italy)

Ioannis Dimitriou

Date: 5-10 September 2016

Institution: Univ. of Patras (Greece)

Daniel Figueiredo

Date: 4-8 April 2016

Institution: Federal Univ. of Rio de Janeiro (Brazil)

Michele Garetto
Date: 4-5 April 2016
Institution: Univ. of Torino (Italy)
Moshe Haviv
Date: 15-19 June 2016
Institution: Univ. of Jerusalem (Israel)
Nidhi Hegde
Date: 10-13 June 2016
Institution: Nokia Bell Labs (France)
Giulio Iacobelli
Date: 11-21 January and 4-8 April 2016
Institution: Federal Univ. of Rio de Janeiro (Brazil)
Philippe Jacquet
Date: 1 December 2016
Institution: Nokia Bell Labs (France)
Jean-Yves Le Boudec
Date: 2 June 2016
Institution: EPFL (Switzerland)
Emilio Leonardi
Date: 6-16 December 2016
Institution: Politecnico di Torino (Italy)
Nelly Litvak
Date: 1-4 December 2016
Institution: Univ. of Twente (Netherlands)
Natalia Markovich
Date: 18-27 June 2016
Institution: Russian Academy of Sciences (Russia)
Evzey Morozov
Date: 21-29 July 2016
Institution: Petrozavodsk Univ. (Russia)
Fernando Ordóñez
Date: 27-30 September
Institution: Univ. of Chile (Chile)
Sreenath Ramanath
Date: 17-27 May 2016
Institution: IIT Bombay (India)
Bruno Ribeiro
Date: 10-20 June 2016
Institution: Carnegie Mellon Univ. (USA)
Daniel Sadoc
Date: 4-8 April 2016
Institution: Federal Univ. of Rio de Janeiro (Brazil)

Matteo Sereno
Date: until March 2016 and 28 Nov-2 Dec 2016
Institution: Univ. of Torino (Italy)
Vinod Sharma
Date: 15-30 November 2016
Institution: IIS Bangalore (India)
Flora Spieksma
Date: 5-7 July 2016
Institution: Univ. of Leiden (Netherlands)
Rajesh Sundaresan
Date: 05-26 May 2016
Institution: IIS Bangalore (India)
Josh Taylor
Date: 24 June 2016
Institution: Univ. of Toronto (Canada)
Don Towsley
Date: 1-3 December 2016
Institution: Univ. of Massachusetts (USA)
Kavitha Voleti Veeraruna
Date: 17-27 May 2016
Institution: IIT Bombay (India)
Uri Yechiali
Date: 15-28 April 2016
Institution: Tel Aviv Univ. (Israel)

9.4.1.2. Post-doc / Ph.D. students

Víctor Bucarey López
Date: 27-30 September 2016
Institution: Univ. of Chile
Ricardo Coelho Silveira
Date: from Sep 2016 until Nov 2016
Institution: Univ. of Rio de Janeiro (Brazil)
Eduardo Hargreaves
Date: 20-23 June 2016
Institution: Univ. of Rio de Janeiro (Brazil)
Yahui Tian
Date: from Jun 2016 until Jul 2016
Institution: Univ. of Texas (USA)

9.4.1.3. Internships

Mikhail Kamalov
Date: from Jun 2016 until Jul 2016
Institution: Saint Petersburg State Univ. (Russia)
Supervisor: Konstantin Avrachenkov

Mohamed Lamghari
Date: from Apr 2016 until Aug 2016
Institution: UNS (France)
Supervisor: Giovanni Neglia
Maksim Mironov
Date: from Aug 2016 until Sept 2016
Institution: MIPT (Russia)
Supervisor: Konstantin Avrachenkov

9.4.2. Visits to International Teams

9.4.2.1. Research Stays Abroad

Konstantin Avrachenkov
Date: 4 - 8 April 2016
Institution: IIT Mumbai (India)
Date: 25 April - 5 May 2016
Institution: Moscow Institute of Physics and Technology and Yandex (Russia)
Date: 10-11 August 2016
Institution: Aaalto Univ. (Finland)
Alain Jean-Marie
Date: 5 - 16 December 2016
Institution: Univ. of Montreal (Canada)
Date: 28 March - 1 April 2016
Institution: Univ. National of Rosario (Argentina)
Date: 3 - 14 April 2016
Institution: Univ. de Chile (Chile)
Arun Kadavankandy
Date: 12-30 April 2016
Institution: Yandex (Russia)
Date: 12-17 July 2016
Institution: IIS Bangalore (India)
Giovanni Neglia
Date: 14 - 22 February; 1 - 4 April; 20 - 25 September; 7 - 10 and 25 - 30 October 2016
Institution: Univ. of Florence (Italy)
Dates: 11 - 16 May; 21 - 23 December 2016
Institution: Univ. of Palermo (Italy)
Dimitra Politaki
Date: 18 October - 2 November and 12 - 20 December 2016
Institution: Univ. of Torino (Italy)

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- S. Alouf and A. Jean-Marie are the general chairs of the 13th SIGMETRICS/PERFORMANCE Joint International Conference on Measurement and Modeling of Computer Systems (ACM SIGMETRICS/IFIP PERFORMANCE 2016, Antibes Juan-les-Pins, France).

10.1.1.2. Member of the Organizing Committees

- A. Kadavankandy, J. Kazhuthuveettil Sreedharan, H. Mykhailenko, D. Politaki, and D. Tsigkari, were in the local organization committee of the 13th SIGMETRICS/PERFORMANCE Joint International Conference on Measurement and Modeling of Computer Systems (ACM SIGMETRICS/IFIP PERFORMANCE 2016, Antibes Juan-les-Pins, France).
- A. Kadavankandy, H. Mykhailenko, D. Politaki, D. Tsigkari, and A. Tuholukova were volunteer students at the 13th SIGMETRICS/PERFORMANCE Joint International Conference on Measurement and Modeling of Computer Systems (ACM SIGMETRICS/IFIP PERFORMANCE 2016, Antibes Juan-les-Pins, France).
- D. Politaki was a volunteer student at the Journées Cloud 2016, Nice, France.
- D. Politaki and E. Vatamidou are members of the organizing committee of the workshop "Monde des mathématiques industrielles (MOMI)", to be held on 27-28 February 2017 at Inria, Sophia Antipolis. Additional information:
- L. Vermeersch was the local organization chair of the 13th SIGMETRICS/PERFORMANCE Joint International Conference on Measurement and Modeling of Computer Systems (ACM SIGMETRICS/IFIP PERFORMANCE 2016, Antibes Juan-les-Pins, France).

10.1.1.3. Member of Conference Steering Committees

- E. Altman chairs the Steering Committee of the Intl. Conference on NETwork Games, COntrol and OPtimization (this year: NETGCOOP 2016, Avignon, France).

10.1.2. Scientific Events Selection

10.1.2.1. Member of the Conference Program Committees

- 13th European Workshop on Performance Engineering (EPEW 2016, Chios, Greece) (**A. Jean-Marie**);
- IEEE Intl. Conference on Computer Communications (INFOCOM 2017, Atlanta, GA, USA) (**G. Neglia**);
- Intl. Conference on NETwork Games, COntrol and OPtimization (NETGCOOP 2016, Avignon, France) (**K. Avrachenkov**);
- 16th Intl. Conference on Next Generation Wired/Wireless Networking (NEW2AN 2016, St. Petersburg, Russia) (**K. Avrachenkov**);
- 10th Intl. Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS 2016, Taormina, Italy) (**K. Avrachenkov**);
- 31st Intl. Symposium on Computer and Information Sciences (ISCIS 2016, Krakow, Poland) (**A. Jean-Marie**);
- 17th Intl. Symposium of Dynamic Games and Applications (ISDG 2016, Urbino, Italy) (**E. Altman**);
- Intl. Workshop on Bio-inspired Security, Trust, Assurance and Resilience (BioSTAR 2016, Fairmont, San Jose, CA, USA) (**E. Altman**);
- 9th Intl. Workshop on Multiple Access Communications (MACOM 2016, Aalborg, Denmark) (**K. Avrachenkov**);
- 5th International Conference on Computational Social Networks (CSoNet 2016, Ho Chi Minh City, Vietnam) (**K. Avrachenkov**);
- 1st Mini-Symposium on Stochastic Models: Methods and Applications (SAMMA 2016, Rhodes, Greece) (**E. Vatamidou**);

- 13th Workshop on Algorithms and Models for the Web Graph (WAW 2016, Montreal, Canada) (**K. Avrachenkov**).

10.1.2.2. Session organizer

- Session on Stochastic Modeling at the 17th Conference of the Société Française de Recherche Opérationnelle et d'Aide à la Décision (ROADEF 2016, Compiègne, France) (**A. Jean-Marie**).

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- *ACM Transactions on Modeling and Performance Evaluation of Computing Systems* (ToMPECS) (**K. Avrachenkov** since 2015).
- *Dynamic Games and Applications* (DGAA) (**E. Altman** since 2011);
- *Elsevier Computer Communications* (COMCOM) (**G. Neglia** since 2014);
- *IEEE/ACM Transactions on Networking* (ToN) (**E. Altman** since 2013);
- AIMS (American Institute of Mathematical Sciences) *Journal of Dynamics and Games* (JDG) (**E. Altman** since 2015);
- *Performance Evaluation* (PEVA) (**K. Avrachenkov** since 2008);
- *Wiley Transactions on Emerging Telecommunications Technologies* (ETT) (**S. Alouf** since July 2016).

10.1.3.2. Member of Advisory Boards

- E. Altman is Member of the advisory board of the international journal *IRAN Journal of Computer Science* published by University of Tabriz. Since 2016.

10.1.4. Invited Talks

MAESTRO members gave the following keynote lectures/plenary speeches (in alphabetical order):

- Eitan Altman gave a keynote talk at *The International Symposium on Ubiquitous Networking, UNet 2016*, Casablanca, May 30 – June 1st, 2016. Title: Game theory applied to SIS Epidemics in Networks.
- Eitan Altman gave a keynote lecture at *ITC 28* in Würzburg on 15 September 2015. Title: Dynamic Games for Analyzing Competition in the Internet.
- Alain Jean-Marie gave a keynote lecture at the *11th Workshop on Retrial Queues (WRQ11)*, in Amsterdam, 31 August – 2 September, 2016. Title: Impatient Customers and Optimal Control.

and the following invited talks (in alphabetical order):

- *Access-time aware cache algorithms*, at UCN'16 Workshop on Future challenges in User-Centric Networks, Antibes Juan-les-Pins, France, 14 June a workshop of ACM Sigmetrics / IFIP Performance 2016 (**G. Neglia**);
- *Distributed spectral decomposition and quantum random walk*, at Workshop on critical and collective effects in graphs and networks, MIPT, Moscow, April 2016 (**K. Avrachenkov**);
- *Distributed spectral decomposition and quantum random walk*, at the 20th Conference of the International Linear Algebra Society (ILAS), Leuven, Belgium, July 2016 (**K. Avrachenkov**);
- *Overview and comparison of random walk based techniques for estimating network averages*, at COSTNET Conference, Ribno, Slovenia, September 2016 (**K. Avrachenkov**);
- *Hitting Times in Markov Chains with Restart and their Applications to Ranking*, at Workshop dedicated to W. Stadje, Osnabruck, Germany, October 2016 (**K. Avrachenkov**).

10.1.5. Leadership within the Scientific Community

- E. Altman is a fellow member of IEEE (Class of 2010).
- E. Altman, A. Jean-Marie and P. Nain are (elected) members of IFIP WG7.3 on "Computer System Modeling". E. Altman is also Member of WG 6.3 of IFIP on Performance of Communication Systems.

10.1.6. Research Administration

E. Altman

- is co-responsible of one of the five themes of the SFR (Structure Fédérative de Recherche) AGORANTIC (in which Inria is a founding member) entitled "Digital Culture and Virtual Societies".

S. Alouf

- was member of the recruitment committee for junior Inria researchers (CR1, CR2);
- is member of the scientific committee of the joint laboratory Inria-Alstom since May 2014.

K. Avrachenkov

- together with Arnaud Legout (DIANA team) and Fabien Gandon (WIMMICS team) is co-responsible of the multi-disciplinary research theme (Action Transversale) "Semantic and Complex Networks" at Inria Sophia Antipolis - Méditerranée.

A. Jean-Marie

- is the scientific coordinator of Inria activities in Montpellier (since 2008); as part of this duty, he represents Inria at the Scientific Council of the Doctoral School "Sciences and Agrosciences" of the Univ. of Avignon, at the Regional Conference of Research Organisms (CODOR);
- is a member of the Steering Committee of the GDR RO, a national research initiative on Operations Research sponsored by the CNRS;
- is Head of project-team MAESTRO since October 2014;

G. Neglia

- is the scientific delegate for European partnerships for Inria Sophia Antipolis – Méditerranée since 2014;
- is member of the Inria COST GTRI (International Relations Working Group of Inria's Scientific and Technological Orientation Council since 2016.

MAESTRO members are in the following committees of Inria Sophia Antipolis-Méditerranée

- CLFP: Training Committee (**S. Alouf**, since November 2014);
- CSD: Doctoral Committee (**S. Alouf**, since February 2006);
- MASTIC: a commission in charge of popularization and regional and internal scientific animation (**D. Politaki**, since July 2016);
- NICE: Invited Researchers Committee (**K. Avrachenkov**, since 2010).

MAESTRO members are in charge of the following tasks for the research center and the project-team:

- Supervision and validation of the project-teams' yearly activity reports (**K. Avrachenkov**, since 2010);
- Organizing the fortnightly PhD seminars of the research center (**D. Politaki**, since November 2016);
- Organizing the fortnightly MAESTRO internal meetings (**J. K. Sreedharan**, since November 2013).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence:

G. Neglia, "Probability", 50.5H, 1st year Water Engineering degree (L3), niv. of Nice Sophia Antipolis (UNS), France.

D. Politaki, "Intro Web", 36H, (L1), UNS, France.

Master:

S. Alouf, "Performance Evaluation of Networks", 31.5H, M2 IFI Ubinet, UNS, France.

A. Jean-Marie, "Foundations of Network Modeling", 12H, MPRI, Univ. Paris Diderot/ENS Ulm/Univ. Paris Saclay, France.

G. Neglia, "Distributed Optimization and Games", 31.5H, M2 IFI Ubinet, UNS, France.

G. Neglia, responsible for the "Winter School on Complex Networks", 22.5H, M1 Computer Science, UNS, France.

K. Avrachenkov, "Random-walk based algorithms for complex network analysis" at "Winter School on Complex Networks", 2H, M1 Computer Science, UNS, France.

10.2.2. Supervision

- PhD defended:

  Alexandre Reiffers-Masson, "Competition over visibility and popularity in on line social networks", UAPV, 12 January 2016, advisors: Eitan Altman and Yezekael Hayel.

  Jithin Kazhuthuveettil Sreedharan, "Sampling and Inference in Complex Networks", Univ. Côte d'Azur, 2 December 2016, advisor: Konstantin Avrachenkov.

  Nessrine Trabelsi, "A Generic Framework for User Association and Interference Management in LTE Cellular Networks", UAPV, 20 December 2016, advisors: Eitan Altman and Rachid El Azouzi.

- PhD in progress:

  Zaid Allybokus, 1 July 2016, advisors: Konstantin Avrachenkov and Lorenzo Maggi (Huawei).

  Arun Kadavankandy, "Random Matrix Theory and Complex Networks," 5 March 2014, advisors: Konstantin Avrachenkov and Laura Cottatellucci (Eurecom).

  Hlib Mykhailenko, "Probabilistic approaches for big data analysis," 1 May 2014, advisors: Fabrice Huet (SCALE team) and Philippe Nain.

  Dimitra Politaki, "Greening data center," 1 February 2016, advisors: Sara Alouf and Fabien Hermenier (UNS).

  Alina Tuholukova, "Caching at the Edge: Distributed Phy-aware Caching Policies for 5G Cellular Networks," 1 July 2016, advisors: Petros Elia (Eurecom) and Giovanni Neglia.

10.2.3. Juries

MAESTRO members participated in the Habilitation (HDR) thesis committees of (in alphabetical order):

- Patrick Loiseau, "Game theory and statistical learning in security, privacy and networks", Univ. Pierre et Marie Curie (Paris), 8 December 2016 (**E. Altman** as reviewer and jury president);

and in the Ph.D. committees of (in alphabetical order):

- Alexandre Reiffers-Masson, "Competition over visibility and popularity in on line social networks", UAPV, 12 January 2016 (**E. Altman** as advisor);
- Nesrine Ben Khalifa, "Evolutionary games with non-uniform interactions and delays", UAPV, 16 December 2016 (**E. Altman** as examiner).
- Mikael Touati, "Cooperative Game Theory and Stable Matchings in Networks", Telecom ParisTech, 1st December 2016 (**E. Altman** as advisor);
- Jithin Kazhuthuveettil Sreedharan, "Sampling and Inference in Complex Networks", Univ. Côte d'Azur, 2 December 2016 (**K. Avrachenkov** as advisor, **A. Jean-Marie** as jury president);
- Nessrine Trabelsi, "A Generic Framework for User Association and Interference Management in LTE Cellular Networks", UAPV, 20 December 2016 (**E. Altman** as advisor);
- Osti Prajwal, "Resource allocation in wireless access network: A queueing theoretic approach", Aalto Univ., Helsinki, Finland, 11 August 2016 (**K. Avrachenkov** as opponent).

10.3. Popularization

Activities are presented in chronological order:

- S. Alouf delivered a conference titled "Comment marche le Web ?" at Lycée Pierre et Marie Curie, Menton, for one classe of high school students (25 November 2016).
- D. Politaki participated to the "Fête de la science" at the Campus Valrose, Nice (13 October 2016) and at the Congress Center, Antibes Juan-les-Pins (22 October 2016). She animated the game "Datagramme" and the programming of Thymio.
- D. Politaki managed two sessions MEDITES in two middle schools (22 November 2016).
- D. Politaki participated to the Thymio competition (26 November 2016) which was organized by Hackathon Women Creativity 2016 in Nice.

D. Politaki is a member of MASTIC, a commission in charge of popularization and regional and internal scientific animation (since July 2016).

10.4. Participation in scientific events

10.4.1. Conferences and workshops

MAESTRO members gave presentations at the following scientific events (in alphabetical order):

- 9th International Conference on Matrix Analytic Methods in Stochastic Models (MAM9), Budapest, Hungary, 28–30 June 2016 (**E. Vatamidou**).
- 4th International workshop on Big Data and Social Networking Management and Security (BDSN), Barcelona, Spain, 5-7 December 2016 (**H. Mykhailenko**).
- 1st International Conference on Reliability, Safety and Security of Railway Systems (RSSR 2016), Paris, France, 28-30 June 2016, (**A. Tuholukova**).
- 2016 Americal Control Conference (ACC 2016), Boston, USA, July 6-8 2016, (**G. Neglia**).

10.4.2. Schools and doctoral courses

MAESTRO members have attended the following events (list in alphabetical order):

- E3-RSD Summer School on "Efficacité Energétique des Réseaux et Systèmes Distribués" (20H), Dinard, France, 23-27 May 2016 (**S. Alouf**, **D. Politaki**);
- WAW 2015 School on complex networks and graph models (16H), Eindhoven, Netherlands, 7-8 December 2015 (**A. Kadavankandy** and **J. K. Sreedharan**).

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Publications of the year

Doctoral Dissertations and Habilitation Theses

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[2] J. K. SREEDHARAN. *Sampling and Inference in Complex Networks*, Université Côte d'Azur, 2016

[3] N. TRABELSI. *A Generic Framework for User Association and Interference Management in LTE Cellular Networks*, UAPV, 2016

Articles in International Peer-Reviewed Journals

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