



Activity Report 2014

## **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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## Project-Team MAESTRO

**Keywords:** Stochastic Modeling, Game Theory, Control Theory, Cellular Networks, Social Networks, Smart Grids

*In collaboration with LIA, Univ. of Avignon (UAPV). MAESTRO is member of the joint laboratory between Inria and Alcatel-Lucent Bell Labs, member of the joint laboratory between Inria and ALSTOM, and member of the French-Indian international joint unit UMI in applied mathematics between Inria, CNRS, and the Indian Institute of Science, Bangalore, India.*

*Creation of the Project-Team: 2003 October 01.*

### 1. Members

#### Research Scientists

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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, P. Nain, 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 network functionalities.



### 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 our 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 we 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 methodological 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. New Software and Platforms

### 5.1. New Software

#### 5.1.1. *ns-3*

**Participants:** Sara Alouf, Abdulhalim Dandoush, Giovanni Neglia.

ns-3 is an open source, C++ based, GPL licensed and highly used discrete-event network simulator. It is targeted primarily for research and educational use. ns-3 is particularly suited for the goals of the research project with ALSTOM Transport (see §7.1.3). New modules have been developed to enable the simulation of the real antennas used by ALSTOM. Also, modules related to the handoff procedure were debugged and modified to fit the proprietary algorithm used by ALSTOM. Another new module allows to simulate the proprietary communication-based train control protocol used by ALSTOM.

### 5.2. Platforms

#### 5.2.1. *Marmote*

**Participants:** Alain Jean-Marie, Issam Rabhi.

In the framework of the ANR MARMOTE, a new software platform dedicated to Markovian modeling is being built. The architecture has been defined so as to be compatible with the software previously developed by members of the project, principally PSI (from the team MESCAL, joint between Inria, Univ. Joseph Fourier (Grenoble) and Institut polytechnique de Grenoble) and XBORNE (from the MAGMAT team of the Univ. Versailles St Quentin). The platform will provide a user interface allowing the modeler to access to a large number of solution methods for generic Markov models as well as optimized methods for specific families of models.

## 6. New Results

### 6.1. Highlights of the Year

E. Altman has received the “Isaacs’ Award” granted by the International Society on Dynamic Games in recognition for his research on dynamic game theory.

M. El Chamie got the Best Session Presentation Award at the IEEE American Control Conference ACC 2014 for the paper “Newton’s method for constrained norm minimization and its application to weighted graph problems,” co-authored with G. Neglia.

THANES is a new French-Brazilian joint-team between MAESTRO and researchers from Univ. Federal do Rio de Janeiro (Brazil) and Carnegie Mellon Univ. (USA). The team investigates network science problems with a particular focus on Online Social Networks.

BEST PAPERS AWARDS :

[43] **Pay few, influence most: Online myopic network covering in 6th IEEE INFOCOM International Workshop on Network Science for Communication Networks (NetSciCom).** K. AVRACHENKOV, P. BASU, G. NEGLIA, B. RIBEIRO, D. TOWSLEY.

[70] **On the Complexity of Optimal Electric Vehicles Recharge Scheduling in 4th IEEE Online Conference on Green Communications (GreenComm).** C. ROTTONDI, G. NEGLIA, G. VERTICALE.

### 6.2. Network Science

**Participants:** Eitan Altman, Konstantin Avrachenkov, Mahmoud El Chamie, Julien Gaillard, Arun Kadamkandy, Jithin Kazhuthuveetil Sreedharan, Hlib Mykhailenko, Philippe Nain, Giovanni Neglia, Yonathan Portilla, Alexandre Reiffers, Vikas Singh, Marina Sokol.

#### 6.2.1. Epidemic models of propagation of content

Epidemic models have received significant attention in the past few decades to study the propagation of viruses, worms and ideas in computer and social networks. In the case of viruses, the goal is to understand how the topology of the network and the properties of its nodes impact the spread of the epidemics. In [38], E. Altman, A. Avritzer and L. Pflieger de Aguiar (Siemens Corporation, Princeton, USA), R. El-Azouzi (Univ. of Avignon), and D. S. Menasche (Federal Univ. of Rio de Janeiro, Brazil) propose rejuvenation as a way to cope with epidemics. Reformatting a computer may solve the problem of virus contamination (but it might be a costly operation) while less dramatic actions may render the computer operational again (even in the presence of the virus). In this work they evaluate the performance gain of such measures as well as sampling for early detection of viruses while these incubate. During incubation, contaminated terminals are infectious and yet, if not detected to be so, they cannot be isolated and treated.

In [60], Y. Hayel (Univ. of Avignon), S. Trajanovski and P. Van Mieghem (Delft Univ. of Technology, The Netherlands), E. Altman, and H. Wang (Delft Institute of Applied Mathematics, The Netherlands), compare solutions involving vaccination to those that involve healing from a selfish point of view of an individual networked user. A game theoretical model is presented and the obtained equilibrium is computed for various types of topologies including the fully connected one, the bipartite graph and a community structure. A novel use of potential games is presented to compute the equilibria.

In [61], L. Maggi and F. De Pellegrini (CREATE-NET, Italy), A. Reiffers, J. J. Herings (Maastricht Univ., The Netherlands) and E. Altman, study a viral diffusion of a content in a multi-community environment. Exploiting time scale separation, the authors are able to reduce the dimensionality of the problem and to compute its limiting behavior in closed form. They further study regulation and cooperative approaches for sharing the cost for fighting the spread of the infection among the communities.

Social networks can have asymmetric relationships. In the online social network Twitter, a follower receives tweets from a followed person but the followed person is not obliged to subscribe to the channel of the follower. Thus, it is natural to consider the dissemination of information in directed networks. In [44], K. Avrachenkov in collaboration with B. Prabhu (LAAS-CNRS), K. De Turck and D. Fiems (Ghent Univ., Belgium) use the mean-field approach to derive differential equations that describe the dissemination of information in a social network with asymmetric relationships. In particular, their model reflects the impact of the degree distribution on the information propagation process. They further show that for an important subclass of their model, the differential equations can be solved analytically.

### 6.2.2. *Bio-Inspired Models for Characterizing YouTube Viewcount*

Bio-inspired models have long been advocated for the dissemination of content in the Internet. How good are such models and how representative are they? In [69], C. Richier, R. El-Azouzi, T. Jimenez, G. Linares (all with Univ. of Avignon), E. Altman and Y. Portilla propose six different epidemic models. These are classified according to various criteria: (i) the size of the target population, which may be constant, or linearly increasing or infinite, (ii) the virality of the content: it is said to be viral if nodes that receive the content participate in retransmitting it (by sharing or embedding). They then collected data on the viewcounts of videos in youtube and examined how well they fit their models. They showed that their six models cover 90% of the videos with an average mean square error of less than 5%. They further studied the capability of using these models to predict the evolution of the viewcount.

### 6.2.3. *Network centrality measures*

Finding quickly top-k lists of nodes with the largest degrees in large complex networks is a basic problem of recommendation systems. If the adjacency list of the network is known (not often the case in complex networks), a deterministic algorithm to solve this problem requires an average complexity of  $O(n)$ , where  $n$  is the number of nodes in the network. Even this modest complexity can be excessive for large complex networks. In [18], K. Avrachenkov and M. Sokol in collaboration with N. Litvak (Twente Univ., The Netherlands) and D. Towsley (Univ. of Massachusetts, Amherst, USA) propose to use a random-walk-based method. They show theoretically and by numerical experiments that for large networks, the random-walk method finds good-quality top lists of nodes with high probability and with computational savings of orders of magnitude. They also propose stopping criteria for the random-walk method that requires very little knowledge about the structure of the network.

In [46], K. Avrachenkov in collaboration with N. Litvak (Twente Univ., the Netherlands) and L. Ostroumova and E. Suyargulova (both from Yandex, Russia) address the problem of quick detection of high-degree entities in large online social networks. The practical importance of this problem is attested by a large number of companies that continuously collect and update statistics about popular entities, usually using the degree of an entity as an approximation of its popularity. They suggest a simple, efficient, and easy to implement two-stage randomized algorithm that provides highly accurate solutions for this problem. For instance, their algorithm needs only one thousand API requests in order to find the top-100 most followed users in Twitter, a network with approximately a billion of registered users, with more than 90% precision. Their algorithm significantly outperforms existing methods and serves many different purposes, such as finding the most popular users or the most popular interest groups in social networks. They show that the complexity of the algorithm is sublinear in the network size, and that high efficiency is achieved in networks with high variability among the entities, expressed through heavy-tailed distributions.

Personalized PageRank is an algorithm to classify the importance of web pages on a user-dependent basis. In [48], K. Avrachenkov and M. Sokol in collaboration with R. van der Hofstad (EURANDOM, The Netherlands) introduce two generalizations of Personalized PageRank with node-dependent restart. The first generalization is based on the proportion of visits to nodes before the restart, whereas the second generalization is based on the proportion of time a node is visited just before the restart. In the original case of constant restart probability, the two measures coincide. They discuss interesting particular cases of restart probabilities and restart distributions. They show that both generalizations of Personalized PageRank have an elegant expression

connecting the so-called direct and reverse Personalized PageRanks that yield a symmetry property of these Personalized PageRanks.

Along with K. Avrachenkov and N. M. Markovich (Institute of Control Sciences, Russian Academy of Sciences, Moscow, Russia), J. K. Sreedharan investigated distribution and dependence of extremes in network sampling processes [47]. This is one of the first studies associating extremal value theory to sampling of large networks. The work showed that for any general stationary samples from the graph (function of node samples) meeting two mixing conditions, the knowledge of bivariate distribution or bivariate copula is sufficient to derive many of its extremal properties. The work proved the usage of a single parameter to find many relevant extremes in networks like order statistics, first hitting time, mean cluster size etc. In particular, correlation in degrees of adjacent nodes are modelled and different random walks, such as PageRank, are studied in detail. This work has been done in the context of Inria Alcatel-Lucent Bell Labs joint laboratory's ADR "Network Science" (see §7.1.2).

#### 6.2.4. Influence maximization in complex networks

Efficient marketing or awareness-raising campaigns seek to recruit a small number,  $w$ , of influential individuals—where  $w$  is the campaign budget—that are able to cover the largest possible target audience through their social connections. In [43] K. Avrachenkov and G. Neglia in collaboration with P. Basu (BBN Technologies, US), B. Ribeiro (CMU, US) and D. Towsley (Univ. of Massachusetts, Amherst, USA) assume that the topology is gradually discovered thanks to recruited individuals disclosing their social connections. They analyze the performance of a variety of online myopic algorithms (i.e. that do not have a priori information on the topology) currently used to sample and search large networks. They also propose a new greedy online algorithm, Maximum Expected Uncovered Degree (MEUD). Their proposed algorithm greedily maximizes the expected size of the cover, but it requires the degree distribution to be known. For a class of random power law networks they show that MEUD simplifies into a straightforward procedure, denoted as MOD because it requires only the knowledge of the Maximum Observed Degree. This work has been done in the context of THANES Joint team (see §8.3.1.1) and Inria Alcatel-Lucent Bell Labs joint laboratory's ADR "Network Science" (see §7.1.2).

In [66] G. Neglia, in collaboration with X. Ye (Politecnico di Torino, Italy), M. Gabielkov and A. Legout (from the DIANA team) consider how to maximize users influence in Online Social Networks (OSNs) by exploiting social relationships only. Their first contribution is to extend to OSNs the model of Kempe, Kleinberg and Tardös on the propagation of information in a social network and to show that a greedy algorithm is a good approximation of the optimal algorithm that is NP-hard. However, the greedy algorithm requires global knowledge, which is hardly practical. Their second contribution is to show on simulations on the full Twitter social graph that simple and practical strategies perform close to the greedy algorithm.

#### 6.2.5. Clustering

Clustering of a graph is the task of grouping its nodes in such a way that the nodes within the same cluster are well connected, but they are less connected to nodes in different clusters. In [45] K. Avrachenkov, M. El Chamie and G. Neglia propose a clustering metric based on the random walks' properties to evaluate the quality of a graph clustering. They also propose a randomized algorithm that identifies a locally optimal clustering of the graph according to the metric defined. The algorithm is intrinsically distributed and asynchronous. If the graph represents an actual network where nodes have computing capabilities, each node can determine its own cluster relying only on local communications. They show that the size of clusters can be adapted to the available processing capabilities to reduce the algorithm's complexity.

#### 6.2.6. Average consensus protocols

In [54], [82], M. El Chamie in collaboration with J. Liu and T. Başar (Univ. of Illinois at Urbana Champaign, USA) studies the performance of a subclass of distributed averaging algorithms where the information exchanged between neighboring nodes (agents) is subject to deterministic uniform quantization. They give the convergence properties of linear averaging due to such quantization (which is a practical concern for many applications) that cause nonlinearity in the system. This is the first attempt to solve the exact model.

In [53], M. El Chamie in collaboration with T. Başar (Univ. of Illinois at Urbana Champaign, USA) considers optimal design strategies in consensus protocols for networks vulnerable to adversarial attacks. They provide a game theoretical model for the problem of a network with an adversary corrupting the control signal with noise. They derive the optimal strategies for both players (the adversary and the network designer) of the resulting game using a saddle point equilibrium solution in mixed strategies.

## 6.3. Wireless Networks

**Participants:** Eitan Altman, Abdulhalim Dandoush, Majed Haddad, Jithin Kazhuthuveetil Sreedharan.

### 6.3.1. Localization in ad-hoc wireless sensors networks

Range-based localization algorithms in wireless sensor networks are more accurate but also more computationally complex than the range-free algorithms. In collaboration with M. S. Elgamel (Univ. of Louisiana, USA), A. Dandoush has revised the Trigonometric based Ad-hoc Localization System (TALS) proposed in the literature. In [83], they propose a new technique to optimize the system: by eliminating the need of solving a linear system of equations via least square methods or its variants or the need for any square root operations, the computational overhead is reduced. Also, a novel modified Manhattan distance is proposed and used in the elimination process ensuring thereby a very good accuracy with less complexity than the basic TALS. Through a mathematical analysis and intensive simulations, the optimized TALS is shown to present superior performance and accuracy results compared to other localization techniques.

### 6.3.2. Channel management

The enhanced Inter Cell Interference Coordination (eICIC) feature has been introduced to solve the interference problem in small cells. It involves two parameters which need to be optimized, namely the Cell Range Extension (CRE) of the small cells and the ABS ratio (ABSr) which defines a mute ratio for the macro cell to reduce the interference it produces. In [72], A. Tall, Z. Altman (Orange Labs, Issy les Moulineaux) and E. Altman propose self-optimizing algorithms for the eICIC. The CRE is adjusted by means of a load balancing algorithm. The ABSr parameter is optimized by maximizing a proportional fair utility of user throughputs. The convergence of the algorithms is proven using Stochastic Approximation theorems. Numerical simulations illustrate the important performance gain brought about by the different algorithms.

Cognitive Radios are proposed as a solution to scarcity of wireless spectrum and one of the main challenges here is to gain knowledge about the spectrum usage by the licensed users, termed as spectrum sensing. In [29], Vinod Sharma (Indian Institute of Science, Bangalore, India) and J. K. Sreedharan study novel algorithms for spectrum sensing which minimize the expected time for spectrum sensing with stringent constraints on the probability of wrong detection. Algorithms are distributed in nature and the work proves that the algorithms are asymptotically optimal distributed sequential hypothesis tests. Along with theoretical guarantees, many practical scenarios in Cognitive Radios are also investigated.

### 6.3.3. Self-Organizing Network (SON)

The fast development of SON technology in mobile networks renders critical the problem of coordinating SON functionalities operating simultaneously. SON functionalities can be viewed as control loops that may need to be coordinated to guarantee conflict free operation, to enforce stability of the network and to achieve performance gain. In [30], A. Tall and Z. Altman (Orange Labs, Issy les Moulineaux), R. Combes (SUPELEC), and E. Altman propose a distributed solution for coordinating SON functionalities. It uses Rosen's concave games framework in conjunction with convex optimization. The SON functionalities are modeled as linear Ordinary Differential Equation (ODE)s. The stability of the system is first evaluated using a basic control theory approach together with strict diagonal concavity notion that originates from game theory. The coordination solution consists in finding a linear map (called coordination matrix) that stabilizes the system of SON functionalities. It is proven that the solution remains valid in a noisy environment using Stochastic Approximation.



## 6.4. Network Engineering Games

**Participants:** Eitan Altman, Ilaria Brunetti, Majed Haddad, Alexandre Reiffers.

### 6.4.1. The association problem

In [57], M. Haddad, S. Habib (Orange Labs, Issy les Moulineaux), and P. Wiecek (Wroclaw Univ. of Technology, Poland) and E. Altman develop a hierarchical Bayesian game framework for automated dynamic offset selection. Users compete to maximize their throughput by picking the best locally serving radio access network (RAN) with respect to their own measurement, their demand and a partial statistical channel state information of other users. In particular, they investigate the properties of a Stackelberg game, in which the base station is a player on its own. They derive analytically the utilities related to the channel quality perceived by users to obtain the equilibria. They study the Price of Anarchy of such system, which is defined as the ratio of the social welfare attained when a network planner chooses policies to maximize social welfare versus the social welfare attained at a Nash/Stackelberg equilibrium when users choose their policies strategically.

### 6.4.2. Cognitive radio

In [26], M. Haddad, P. Wiecek (Wroclaw Univ. of Technology, Poland), O. Habachi and Y. Hayel (both with Univ. of Avignon) propose a game theoretical approach that allows cognitive radio pairs, namely the primary user (PU) and the secondary user (SU), to update their transmission powers and frequencies simultaneously. Specifically, a Stackelberg game model in which individual users attempt to hierarchically access to the wireless spectrum while maximizing their energy efficiency was addressed. A thorough analysis of the existence, uniqueness and characterization of the Stackelberg equilibrium was conducted. In particular, it was shown that a spectrum coordination naturally occurs when both actors in the system decide sequentially about their powers and their transmitting carriers. As a result, spectrum sensing in such a situation turns out to be a simple detection of the presence/absence of a transmission on each sub-band. An algorithmic analysis on how the PU and the SU can reach such a spectrum coordination using an appropriate learning process is provided.

In [59], the same authors present a hierarchical game to model distributed joint power and channel allocation for multi-carrier energy efficient cognitive radio systems. A thorough analysis of the existence, uniqueness and characterization of the Stackelberg equilibrium is conducted. It was proved that, at the Stackelberg equilibrium, each of the two users transmits on only one carrier depending on the fading channel gains. This results contrast with capacity-based approaches in which a certain number of carriers is exploited depending on the channel gains. Interestingly, it was shown that, for the vast majority of cases, introducing a certain degree of hierarchy in a multi-carrier system induces a natural coordination pattern where users have incentive to choose their transmitting carriers in such a way that they always transmit on orthogonal channels. Analytical results were provided for assessing and improving the performances in terms of energy efficiency between the non-cooperative game with synchronous decision makers and the proposed Stackelberg game.

### 6.4.3. Routing Games

In [39], E. Altman, J. Kuri (Indian Institute of Science, Bangalore, India) and R. El-Azouzi (Univ. of Avignon) study a routing game that models competition over a simple network with losses. Packets may be lost in the network due to either congestion losses or to channel random losses. They compute the equilibrium and establish its properties. They identify a Braess type paradox in which by adding a link the loss probabilities of all players increase.

G. Accongiagioco (Institute for Advanced Studies, Lucca, Italy), E. Altman, E. Gregori (Italian National Research Council, Italy) and L. Lenzini (Univ. of Pisa, Italy) analyze in [36] the decisions taken by an Autonomous System (AS) when joining the Internet. They first define a realistic model for the interconnection costs incurred and then they use this cost model to perform a game theoretic analysis of the decisions related to the creation of new links in the Internet. The proposed model does not fall into the standard category of routing games, hence they devise new tools to solve it by exploiting peculiar properties of the game. They prove analytically the existence of multiple equilibria for specific cases, and provide an algorithm to compute the stable ones. The analysis of the model's outcome highlights the existence of a Price of Anarchy and a Price of Stability.

#### 6.4.4. Network neutrality and collusion

Representatives of several Internet access providers have expressed their wish to see a substantial change in the pricing policies of the Internet. In particular, they would like to see content providers pay for use of the network, given the large amount of resources they use. This would be in clear violation of the “network neutrality” principle that had characterized the development of the wireline Internet. In [14], E. Altman, M. K. Hanawal (former PhD student in MAESTRO) and R. Sundaresan (Indian Institute of Science, Bangalore, India) proposed and studied possible ways of implementing such payments and of regulating their amount. The results were reported already in a previous report, but were substantially revised during the period of this project.

#### 6.4.5. Competition over popularity in social networks

We have pursued our analysis of competition over popularity and visibility in social networks. In [68], A. Reiffers and E. Altman, together with Y. Hayel (Univ. of Avignon) study a game model that arises when the rate of transmission of packets of each source can be accelerated in order to optimize a weighted sum of its acceleration cost and the expected number of its contents on the timelines of those who follow that content. While this paper considers equilibrium within static policies (in which the acceleration rate does not change in time), the same authors study in [51] the structure of dynamic equilibrium policies which are allowed to change as a function of the time (or of the state). A problem with a similar tradeoff is studied by E. Altman in a mobile context in [13] where the question of accelerating the transmission rate of content arises in a context of competition over content where it is assumed that if a content reaches a given destination then that destination will not be interested any more in receiving competing content.

In [67], A. Reiffers, E. Altman and Y. Hayel (Univ. of Avignon) extend the work in [68], and model the situation in which several social networks are available and a source may control not only the rate of transmission (acceleration) but may also decide how to split its content to the various social networks.

A competition over the timing of the transmission of a content was studied by E. Altman and N. Shimkin (Israel Institute of Technology, Israel) in [41]. Uniqueness of a symmetric equilibrium was established under the assumption of Poisson arrival of requests.

### 6.5. Green Networking and Smart Grids

**Participants:** Sara Alouf, Eitan Altman, Alberto Benegiamo, Ioannis Dimitriou, Majed Haddad, Alain Jean-Marie, Giovanni Neglia.

#### 6.5.1. Energy efficiency in wireless networks

In [25], M. Haddad, P. Wiecek (Wroclaw Univ. of Technology, Poland), O. Habachi and Y. Hayel (both with Univ. of Avignon) investigated the achievable performances of multi-carrier energy efficient power control game. Both the simultaneous-move and the hierarchical games were addressed. For the first time, the analytical closed-form expressions of the spectrum coordination and the spectral efficiency of such models was derived. Results indicate that the spectrum coordination capability induced by the power control game model enables the wireless network to enjoy the energy efficiency improvement while still achieving a high spectral efficiency.

In [58], the same authors studied energy efficiency of heterogeneous networks for both sparse and dense (two-tier and multi-tier) small cell deployments. The problem is formulated as a hierarchical (Stackelberg) game in which the macro cell is the leader whereas the small cell is the follower. Both players want to strategically decide on their power allocation policies in order to maximize the energy efficiency of their registered users. A backward induction method has been used to obtain a closed-form expression of the Stackelberg equilibrium. It was shown that the energy efficiency is maximized when only one sub-band is exploited for the players of the game depending on their fading channel gains.



In [34], R. A. Vaca Ramirez and J. S. Thompson (Univ. of Edinburgh, UK), E. Altman and V. M. Ramos Ramos (Univ. Autonoma Metropolitana, Mexico) aim to reduce the power expenditure in the reverse link during low network load periods, by allocating extra resource blocks (RBs) to the mobile users. This is in contrast with other approaches in which resources are reduced in hours of low energy consumption. The user's rate demands are split among its allocated RBs in order to transmit in each of them by using a low level modulation order. In this low SINR regime the transmission is much more energy efficient since the log appearing in Shannon formula is in close to linear. We model the bandwidth expansion (BE) process by a game theory framework derived from the concept of stable marriage with incomplete lists (SMI).

P. Wiecek (Wroclaw Univ. of Technology, Poland) and E. Altman consider in [42] dynamic Multiple Access games between a random number of players competing over collision channels. Each of several mobiles involved in an interaction determines whether to transmit at a high or at a low power. High power decreases the lifetime of the battery but results in smaller collision probability. They formulated this game as an anonymous sequential game with undiscounted reward and computed the equilibrium [42]. The internal state of a player corresponds to the amount of energy left in the battery and the actions correspond to the transmission power.

I. Dimitriou investigated in [52] the power management of mobile devices, using a variant of an M/G/1 queue with probabilistic inhomogeneous multiple vacations and generalized service process. Under the vacation scheme, at the end of a vacation the server goes on another vacation, with a different probability distribution, if during the previous vacation there have been no arrivals. The modified vacation policy depends on the initial vacation interval and the server selects randomly over  $M$  such vacation policies. The theoretical system can be applied for modeling the power saving mode of mobile devices in modern wireless systems. Moreover, the form of the service process properly describes the incremental redundancy retransmission scheme that provides different types of retransmissions in such systems. Steady state analysis is investigated, energy and performance metrics are obtained and used to provide numerical results that are also validated against simulations.

### 6.5.2. Energy efficiency in delay tolerant networks

Energy efficiency in mobile networks is further studied in [28] where L. Sassatelli (Univ. of Nice Sophia Antipolis), A. Ali, M. Panda and T. Chahed (all with Telecom SudParis) and E. Altman tackle the issue of reliable transport in Delay-Tolerant mobile ad hoc Networks, that are operated by some opportunistic routing algorithm. We propose a reliable transport mechanism that relies on Acknowledgements (ACK) and coding at the source. The various versions of the problem depending on buffer management policies are formulated, and a fluid model based on a mean-field approximation is derived for the designed reliable transport mechanism. This model allows to express both the mean file completion time and the energy consumption up to the delivery of the last ACK at the source.

### 6.5.3. Modeling of a smart green base station

S. Alouf, I. Dimitriou A. Jean-Marie have considered the modeling of wireless communication base stations with autonomous energy supply (solar, wind). They proposed and analyzed a queueing model to assess performance of a base station fully powered by renewable energy sources. The system operates in a finite state Markovian random environment that properly describes the intermittent nature of renewable energy sources and the data traffic. The base station is considered to be "smart" in the sense that it is able to dynamically adjust its coverage area, controlling thereby the traffic rate and its energy consumption. They show how the matrix-analytic formalism enables to construct and study the performance of a smart green base station operating in random environment. More precisely, the behavior of such a system is described by a five-dimensional Markov process, which is a homogeneous finite Quasi Birth-Death (QBD) process. Several existing algorithms can be used in order to obtain the stationary probability vector, which is the basis for the calculation of interesting performance metrics. This work is on-going and has not been submitted for publication yet.

### 6.5.4. Direct Load Control

Balancing energy demand and production is becoming a more and more challenging task for energy utilities also because of the larger penetration of renewable energies which are more difficult to predict and control.

While the traditional solution is to dynamically adapt energy production to follow the time-varying demand, a new trend is to drive the demand itself. Most of the ongoing actions in this direction involve greedy energy consumers, like industrial plant, supermarkets or large buildings. Pervasive communication technologies may allow in the near future to push further the granularity of such approach, by having the energy utility interacting with residential appliances. In [65] and in its extension [64], G. Neglia, in collaboration with G. Di Bella, L. Giarré and I. Tinnirello (Univ. of Palermo, Italy) study large scale direct control of inelastic home appliances whose energy demand cannot be shaped, but simply deferred. Their solution does not suppose any particular intelligence at the appliances. The actuators are rather smart plugs (simple devices with local communication capabilities that can be inserted between appliances plugs and power sockets) and are able to interrupt/reactivate power flow through the plug. A simple control message can be broadcast to a large set of smart plugs for probabilistically enabling or deferring the activation requests of a specific load type in order to satisfy a probabilistic bound on the aggregated power consumption. The control law and the most important performance metrics can be easily derived analytically.

### 6.5.5. Charge of Electric Vehicles

The massive introduction of Electric Vehicles (EVs) is expected to significantly increase the power load experienced by the electrical grid, but also to foster the exploitation of renewable energy sources: if the charge process of a fleet of EVs is scheduled by an intelligent entity such as a load aggregator, the EVs' batteries can contribute in flattening energy production peaks due to the intermittent production patterns of renewables by being recharged when energy production surpluses occur. To this aim, time varying energy prices are used, which can be diminished in case of excessive energy production to incentivize energy consumption (or increased in case of shortage to discourage energy utilization). In [70] G. Neglia, in cooperation with C. Rottondi and G. Verticale (Politecnico di Milano, Italy), evaluate the complexity of the optimal scheduling problem for a fleet of EVs aimed at minimizing the overall cost of the battery recharge in presence of time-variable energy tariffs. The scenario under consideration is a fleet owner having full knowledge of customers' traveling needs at the beginning of the scheduling horizon. They prove that the problem has polynomial complexity, provide complexity lower and upper bounds, and compare its performance to a benchmark approach which does not rely on prior knowledge of customers' requests, in order to evaluate whether the additional complexity required by the optimal scheduling strategy w.r.t. the benchmark is worthy the achieved economic advantages. Numerical results show considerable cost savings obtained by the optimal scheduling strategy.

## 6.6. Content-Oriented Systems

**Participants:** Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Nicaise Choungmo Fofack, Abdulhalim Dandoush, Majed Haddad, Alain Jean-Marie, Philippe Nain, Giovanni Neglia, Marina Sokol.

### 6.6.1. Modeling modern DNS caches

N. Choungmo Fofack and S. Alouf have pursued their study of the modern behavior of DNS (Domain Name System) caches. The entire set of traces collected in 2013 by Inria's IT services in Sophia Antipolis at one of the Inria's DNS caches have been processed and analyzed with the help of N. Nedkov (4-month intern in MAESTRO). This allowed to strengthen the validation of the theoretical models developed in 2013 (see [86]). On the other hand, parts of [86] have been revisited and derived under more general assumptions. As a direct consequence, the exact analysis derived on linear cache networks is extended to a large class of hierarchical cache networks called *linear-star* networks which include linear and two-level tree/star networks. In addition, closed-form expressions for the cache consistency measures (refresh rate and correctness probability) are provided under the assumption that contents requests and updates occur according to two independent renewal processes.

### 6.6.2. Analysis of general and heterogeneous cache networks

There has been considerable research on the performance analysis of *on-demand* caching replacement policies like Least-Recently-Used (LRU), First-In-First-Out (FIFO) or Random (RND). Much progress has been made

on the analysis of a single cache running these algorithms. However it has been almost impossible to extend the results to networks of caches. In [22], N. Choungmo Fofack, P. Nain and G. Neglia, in collaboration with D. Towsley (Univ. of Massachusetts, Amherst, USA), introduce a Time-To-Live (TTL) based caching model, that assigns a timer to each content stored in the cache and redraws it every time the content is requested (at each hit/miss). They derive the performance metrics (hit/miss ratio and rate, occupancy) of a TTL-based cache in isolation fed by stationary and ergodic request processes with general TTL distributions. Moreover they propose an iterative procedure to analyze TTL-based cache networks under the assumptions that requests are described by *renewal processes* (that generalize Poisson processes or the standard IRM assumption). They validate the theoretical findings through event-driven and Monte-Carlo simulations based on the Fourier Amplitude Sensitivity Test to explore the space of the input parameters. The analytic model predicts remarkably well all metrics of interest with relative errors smaller than 1%.

Jointly with M. Badov, M. Dehghan, D. L. Goeckel and D. Towsley (all with the Univ. of Massachusetts, Amherst, USA), N. Choungmo Fofack proposes in [81] approximate models to assess the performance of a cache network with arbitrary topology where nodes run the Least Recently Used (LRU), First-In First-Out (FIFO), or Random (RND) replacement policies on arbitrary size caches. The authors take advantage of the notions of “cache characteristic time” and “Time-To-Live (TTL)-based cache” to develop a unified framework for approximating metrics of interest of interconnected caches. This approach is validated through event-driven simulations, and when possible, compared to the existing *a-NET* model.

### 6.6.3. Data placement and retrieval in distributed/peer-to-peer systems

Distributed systems using a network of peers have become an alternative solution for storing data. These systems are based on three pillars: data fragmentation and dissemination among the peers, redundancy mechanisms to cope with peers churn and repair mechanisms to recover lost or temporarily unavailable data. In previous years, A. Dandoush, S. Alouf and P. Nain have studied the performance of peer-to-peer storage systems in terms of data lifetime and availability using the traditional redundancy schemes. This work has now been published in [23].

A. Jean-Marie and O. Morad (Univ. Montpellier 2) have proposed a control-theoretic model for the optimization of prefetching in the context of hypervideo or, more generally, connected documents. The user is assumed to move randomly from document to document, and the controller attempts at downloading in advance the documents accessed. A penalty is incurred when the document is not completely present. The model is flexible in the sense that it allows several variants for the network model and the cost metric [63]. They have proposed exact algorithms and heuristics for the solution of this problem, and compared them on a benchmark of different user behaviors [62].

The question of whether it is possible to prefetch documents so that the user never experiences blocking, has been modeled with a “cops-and-robbers” game jointly with F. Fomin (Univ. Bergen), F. Giroire and N. Nisse (both from Inria project-team COATI) and D. Mazauric (former PhD student in MAESTRO and MASCOTTE) [24] (see also MAESTRO’s 2011 activity report).

### 6.6.4. Streaming optimization

In streaming applications such as youtube, packets have to be played at the destination at the same rate they were created. If a packet is not available at the destination when it has to be played then a starvation occurs. This results in an unpleasant frozen screen and in an interruption in the video. To decrease the probability of a starvation the destination first waits till it has received some target number of packets and only then starts to play them. In [32], E. Altman and M. Haddad together with Y. Xu (Fudan Univ. China), R. El-Azouzi and T. Jimenez (Univ. of Avignon), and S.-E. Elayoubi (Orange Labs, Issy les Moulineaux) compute the starvation probability as a function of the initial buffering and study tradeoffs between the two performance measures: starvation probabilities and the pre-buffering delay.

### 6.6.5. Stochastic geometry and network coding for distributed storage

In [37] E. Altman and K. Avrachenkov in collaboration with J. Goseling (Twente Univ., The Netherlands) consider storage devices located in the plane according to a general point process and specialize the results for

the homogeneous Poisson process. A large data file is stored at the storage devices, which have limited storage capabilities. Hence, they can only store parts of the data. Clients can contact the storage devices to retrieve the data. The expected costs of obtaining the complete data under uncoded or coded data allocation strategies are compared. It is shown that for the general class of cost measures where the cost of retrieving data is increasing with the distance between client and storage devices, coded allocation outperforms uncoded allocation. The improvement offered by coding is quantified for two more specific classes of performance measures. Finally, the results are validated by computing the costs of the allocation strategies for the case that storage devices coincide with currently deployed mobile base stations.

## 6.7. Advances in Methodological Tools

**Participants:** Eitan Altman, Konstantin Avrachenkov, Ilaria Brunetti, Ioannis Dimitriou, Mahmoud El Chamie, Majed Haddad, Alain Jean-Marie, Philippe Nain, Giovanni Neglia.

### 6.7.1. Queueing theory

In [21] K. Avrachenkov and P. Nain in collaboration with U. Yechiali (Tel Aviv Univ., Israel) study a retrial queueing system with two independent Poisson streams of jobs flowing into a single-server service system, having a limited common buffer that can hold at most one job. If a type- $i$  job ( $i = 1, 2$ ) finds the server busy, it is blocked and routed to a separate type- $i$  retrial (orbit) queue that attempts to re-dispatch its jobs at its specific Poisson rate. This creates a system with three dependent queues. Such a queueing system serves as a model for two competing job streams in a carrier sensing multiple access system. They study the queueing system using multi-dimensional probability generating functions, and derive its necessary and sufficient stability conditions while solving a Riemann-Hilbert boundary value problem. Various performance measures are calculated and numerical results are presented. In particular, numerical results demonstrate that the proposed multiple access system with two types of jobs and constant retrial rates provides incentives for the users to respect their contracts.

In [19] K. Avrachenkov in collaboration with E. Morozov (Petrozavodsk State Univ., Russia) consider a finite buffer capacity GI/GI/c/K-type retrial queueing system with constant retrial rate. The system consists of a primary queue and an orbit queue. The primary queue has  $c$  identical servers and can accommodate up to  $K$  jobs (including  $c$  jobs under service). If a newly arriving job finds the primary queue to be full, it joins the orbit queue. The original primary jobs arrive to the system according to a renewal process. The jobs have i.i.d. service times. The head of line job in the orbit queue retries to enter the primary queue after an exponentially distributed time independent of the length of the orbit queue. Telephone exchange systems, medium access protocols, optical networks with near-zero buffering and TCP short-file transfers are some telecommunication applications of the proposed queueing system. The model is also applicable in logistics. They establish sufficient stability conditions for this system. In addition to the known cases, the proposed model covers a number of new particular cases with the closed-form stability conditions. The stability conditions that they obtained have clear probabilistic interpretation.

In [20] K. Avrachenkov in collaboration with E. Morozov and R. Nekrasova (Petrozavodsk State Univ., Russia) and B. Steyaert (Ghent Univ., Belgium) study a retrial queueing system with  $N$  classes of customers, where a class- $i$  blocked customer joins orbit  $i$ . Orbit  $i$  works like a single-server queueing system with (exponential) constant retrial time (with rate  $\mu_{0i}$ ) regardless of the orbit size. Such a system is motivated by multiple telecommunication applications, for instance wireless multi-access systems, and transmission control protocols. First, they present a review of some corresponding recent results related to a single-orbit retrial system. Then, using a regenerative approach, they deduce a set of necessary stability conditions for such a system. They will show that these conditions have a very clear probabilistic interpretation. They also performed a number of simulations to show that the obtained conditions delimit the stability domain with a remarkable accuracy, being in fact the (necessary and sufficient) stability criteria, at the very least for the 2-orbit M/M/1/1-type and M/Pareto/1/1-type retrial systems that they focus on.

In [75], I. Dimitriou investigates a single server system accepting two types of retrial customers and paired services. The service station can handle at most one customer, and if upon arrival a customer finds the server busy it is routed to an infinite capacity orbit queue according to its type. Upon a service completion epoch, if at least one orbit queue is non-empty, the server seeks to find customers from the orbits. If both orbit queues are non-empty, the seeking process will bring to the service area a pair of customers, one from each orbit. If only one is non-empty, then a customer from this orbit queue will be brought to the service area. However, if a primary customer arrives during the seeking process it will occupy the server immediately. It is shown that the joint stationary orbit queue length distribution at service completion epochs, can be determined via transformation to a Riemann boundary value problem. Stability condition is investigated, while an extension of the model is also discussed and analyzed. Numerical results are obtained and yield insight into the behavior of the system. The theoretical system can be used to model a relay node for two connections in wireless communication, where network coding is used.

When individuals have to take a decision on whether or not to join a queue, one may expect to have threshold equilibria in which customers join the queue if its size is smaller than a threshold and do not join if it exceeds the threshold. In [74], P. Wiecek (Wroclaw Univ. of Technology, Poland), E. Altman and A. Ghosh (Univ. of Pennsylvania, USA) have studied queueing in which the congestion cost per user decreases in the queue size. An example for such a situation is multicast communication where all individuals that participate in the multicast session share the transmission cost. They showed that many equilibria exist and computed the asymptotic system behavior as the arrival rate of individuals grows.

### 6.7.2. Markov processes

In [16] K. Avrachenkov in collaboration with A. Eshragh (Univ. of Adelaide, Australia) and J. Filar (Flinders Univ., Australia) present some algebraic properties of a particular class of probability transition matrices, namely, Hamiltonian transition matrices. Each matrix  $P$  in this class corresponds to a Hamiltonian cycle in a given graph  $G$  on  $n$  nodes and to an irreducible, periodic, Markov chain. They show that a number of important matrices traditionally associated with Markov chains, namely, the stationary, fundamental, deviation and the hitting time matrix all have elegant expansions in the first  $n - 1$  powers of  $P$ , whose coefficients can be explicitly derived. They also consider the resolvent-like matrices associated with any given Hamiltonian cycle and its reverse cycle and prove an identity about the product of these matrices. As an illustration of these analytical results, they exploit them to develop a new heuristic algorithm to determine a non-Hamiltonicity of a given graph.

### 6.7.3. Control theory

In [17] K. Avrachenkov and O. Habachi (former post-doc in MAESTRO) in collaboration with A. Piunovskiy and Y. Zhang (both from the Univ. of Liverpool, UK) investigate infinite-horizon deterministic optimal control problems with both gradual and impulsive controls, where any finitely many impulses are allowed simultaneously. Both discounted and long-run time-average criteria are considered. They establish very general and at the same time natural conditions, under which the dynamic programming approach results in an optimal feedback policy. The established theoretical results are applied to the Internet congestion control, and by solving analytically and non-trivially the underlying optimal control problems, they obtain a simple threshold-based active queue management scheme, which takes into account the main parameters of the transmission control protocols, and improves the fairness among the connections in a given network.

### 6.7.4. Game theory

#### 6.7.4.1. Estimating the Shapley-Shubik index

In [15] K. Avrachenkov in collaboration with L. Cottatellucci (EURECOM) and L. Maggi (CREATE-NET, Italy) consider simple Markovian games, in which several states succeed each other over time, following an exogenous discrete-time Markov chain. In each state, a different simple static game is played by the same set of players. They investigate the approximation of the Shapley-Shubik power index in simple Markovian games (SSM). They prove that an exponential number of queries on coalition values is necessary for any deterministic algorithm even to approximate SSM with polynomial accuracy. Motivated by this, they propose and study three



randomized approaches to compute a confidence interval for SSM. They rest upon two different assumptions, static and dynamic, about the process through which the estimator agent learns the coalition values. Such approaches can also be utilized to compute confidence intervals for the Shapley value in any Markovian game. The proposed methods require a number of queries, which is polynomial in the number of players in order to achieve a polynomial accuracy.

#### 6.7.4.2. Evolutionary games

Evolutionary games attempt to explain the evolution of species and the dynamics of competition. The player's utility is called "fitness" and a larger fitness indicates a larger rate of reproducibility. In standard evolutionary games, one studies interactions between individuals each of which is considered as a player. In [49], I. Brunetti, E. Altman, and R. El-Azouzi (Univ. of Avignon) argue that in many situations both in biology as well as in networking, one cannot attribute a fitness to an individual but rather to a group of individuals that behaves as an altruistic entity. For example, in a hive of bees it is only the queen that reproduces and thus one cannot model a single bee as a selfish player. They present new definitions for evolutionary games for such situations and study their equilibrium.

This, as well as other considerations in multi-population evolutionary games, is applied in [56] by H. Gaiech and R. El-Azouzi (Univ. of Avignon), M. Haddad, E. Altman and I. Mabrouki (Univ. of Manouba, Tunisia) to Multiple Access Control for which the equilibrium is explicitly computed.

In [84] E. Altman presents a summary of the foundations of classical evolutionary games addressed to a wide public. Both the equilibrium notion of ESS (Evolutionary Stable Strategy) as well as the replicator dynamics (which describes the non-equilibrium behavior) are presented.

#### 6.7.4.3. Sequential Anonymous Games

Stationary anonymous sequential games are a special class of games that combines features from both population games (infinitely many players) with stochastic games. It allows studying competition in complex systems where each individual belongs to a community (which we call individual state) which may change in time as a result of actions taken by the individual. Unlike standard evolutionary games, a player does not just optimize its immediate reward (fitness) but some long term reward over the time. P. Wiecek (Wroclaw Univ. of Technology, Poland) and E. Altman proved in [42] the existence of an equilibrium for the general model and studied the two applications. The first one is described in §6.5.1.

The second application is a maintenance repair problem: each of a large number of cars can decide whether to behave gently or to drive fast. By driving fast it takes larger risks for having an accident. The probability of an accident depends on the fraction of drivers that drive fast. An internal state of the car is either good (g) or bad (b). A car gets to a state b as a result of an accident and then it has some penalty and costs for repair. The advantage of driving fast is reducing delay costs. This problem is formulated as a sequential anonymous game and its equilibrium is computed. The computation makes use of the linear structure of both the transition probabilities and the immediate fitness in the global state.

#### 6.7.5. Optimization

In [55] M. El Chamie and G. Neglia provide a methodology for solving smooth norm optimization problems under some linear constraints using the Newton's method. This problem arises in many machine learning and graph optimization applications. They show how Newton's method significantly outperforms gradient methods both in terms of convergence speed and in terms of robustness to the step size selection.

## 7. Bilateral Contracts and Grants with Industry

### 7.1. Bilateral Contracts with Industry

MAESTRO members are involved in the

- Inria Alcatel-Lucent 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 §7.1.1 and §7.1.2).
- Inria ALSTOM joint laboratory: the joint laboratory consists of four projects. MAESTRO members participate in project P11 (see §7.1.3).

### 7.1.1. ADR “Self-Organized Networks in Wireless” (October 2012 – December 2015)

**Participants:** Eitan Altman, Majed Haddad.

- Contractor: Alcatel-Lucent Bell Labs (<http://www.alcatel-lucent.com/bell-labs>)
- Collaborators: Laurent Rouillet (coordinator), Véronique Capdevielle.

Coordinator for Inria: Bruno Gaujal (team MESCAL).

During the investigations carried out within this ADR, in collaboration with Alcatel-Lucent Bell Labs and WIRELESS ENB teams (System Engineering and Modem), M. Haddad and E. Altman have proposed three technical solutions to the LTE Mobility State Estimation problem. In particular,

- Three patents have been submitted and filed (two in 2013, and one in 2014);
- A white paper written by the joint team (Inria/Bell-Labs and Wireless SE) summarizing the theoretical baseline of the methods, their performances, as well as the implementation issues, is documented.

These solutions have been set up between Inria and Alcatel-Lucent Bell Labs iteratively after numerous meetings, in order to cope with the product requirements. This work is on-going and has not been submitted for publication yet.

### 7.1.2. ADR “Network Science” (January 2013 – January 2016)

**Participants:** Konstantin Avrachenkov [coordinator], Jithin Kazhuthuvelil Sreedharan, Philippe Nain, Giovanni Neglia, Marina Sokol.

- Contractor: Alcatel-Lucent Bell Labs (<http://www.alcatel-lucent.com/bell-labs>)
- 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 (see §6.2.3) and models of influence/information propagation over the complex networks (see §6.2.4).

### 7.1.3. Project P11 “Data Communication Network Performance” (December 2013 – May 2016)

**Participants:** Sara Alouf [coordinator], Konstantin Avrachenkov, Abdulhalim Dandoush, Philippe Nain, Giovanni Neglia.

- Contractor: ALSTOM Transport (<http://www.alstom.com/transport/>)
- Collaborators: Pierre Cotelle, Pierre Dersin, Sébastien Simoens (coordinator).

The objective of this study is to build a simulation platform (see §5.1.1) 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.

## 7.2. Bilateral Grants with Industry

### 7.2.1. “Multi-Objective Optimization for LTE-Advanced Networks” (December 2012 – November 2015)

**Participant:** Eitan Altman.

- **Contractor:** Orange Labs (<http://www.orange.com/en/innovation>)
- **Collaborators:** Zwi Altman, Abdoulaye Tall.

The objective of this Cifre thesis is threefold: (1) to develop solutions based on stochastic approximations and optimal control for the optimization and setting of LTE-Advanced Networks; (2) to develop queuing models to capture the dynamics of the traffic and the physical layer mechanisms (e.g. relay, MIMO, scheduling); and (3) to apply the developed methods to engineering problems such as the interference management, load balancing, optimization of coverage and capacity, and mobility management.

## 8. Partnerships and Cooperations

### 8.1. National Initiatives

#### 8.1.1. 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 - December 2016

Coordinator: Alain Jean Marie (Inria)

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

Abstract: ANR MARMOTE aims 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>

### 8.2. European Initiatives

#### 8.2.1. FP7 & H2020 Projects

##### 8.2.1.1. CONGAS

**Participants:** Eitan Altman, Konstantin Avrachenkov, Ilaria Brunetti, Yonathan Portilla, Alexandre Reiffers, Vikas Singh.

Project title: Dynamics and coevolution in multi level strategic interaction games

Type: FP7

Challenge: Future and Emerging Technologies

Instrument: Specific Targeted Research Project

Objective: FET Proactive: Dynamics of Multi-Level Complex Systems (DyM-CS)

Duration: October 2012 - September 2015

Coordinator: Francesco De Pellegrini (CREATE-NET)



Scientific Coordinator: Eitan Altman (Inria)

Other partners: Center for Research and Telecommunication Experimentation for Network Communities (Italy), Univ. d'Avignon et des Pays de Vaucluse (France), Technische Univ. Delft (The Netherlands), Imperial College of Science, Technology and Medicine (United Kingdom), Univ. di Pisa (Italy) and Technion - Israel Institute of Technology (Israel)

Inria contact: Konstantin Avrachenkov

Abstract: CONGAS will develop new mathematical models and tools, rooted in game theory, for the analysis, prediction and control of dynamical processes in complex systems. It will provide a coherent theoretical framework for understanding the emergence of structure and patterns in these systems, accounting for interactions spanning various scales in time and space, and acting at different structural and aggregation levels.

MAESTRO's task is to develop game theoretic models to model (a) the formation of technological and social network; (b) the routing for competing agents; and (c) the competition of information in social networks.

<http://www.congas-project.eu/>

### 8.2.2. Collaborations in European Programs, except FP7 & H2020

Program: 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

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.

Keywords: Service oriented internet, cloud services, autonomous control, reliability, pricing.

Website: <http://www.cost-across.nl/>

### 8.2.3. Collaborations with Major European Organizations

European Space Operations Centre: European Space Agency, Darmstadt (Germany)

Application of a BitTorrent-like data distribution model to mission operations. In the framework of this project with ESA we cooperate with Thales-Alenia Space (France) and with Teletel S.A. (Greece).

## 8.3. International Initiatives

### 8.3.1. Inria Associate Teams

#### 8.3.1.1. THANES

**Participants:** Eitan Altman, Konstantin Avrachenkov, Jithin Kazhuthuvelil Sreedharan, Philippe Nain, Giovanni Neglia, Alexandre Reiffers.

Title: THEory and Application of NETWORK Science

Inria principal investigator: Giovanni Neglia

International Partner (Institution - Laboratory - Researcher):

Univ. Federal do Rio de Janeiro (Brazil) - Department of Computer and Systems Engineering - Daniel Ratton Figueiredo

Duration: 2014 - 2016

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.

#### 8.3.1.2. GANESH

**Participants:** Eitan Altman, Konstantin Avrachenkov.

Title: GAMES, OptimizatiON and Analysis of NETworkS THEory and Applications

Inria principal investigator: Eitan Altman

International Partners (Institution - Laboratory - Researcher):

IISc Bangalore (India) - Electrical Communication Engineering - Anurag Kumar

IIT Mumbai (India) - Department of Electrical Engineering - Vivek Borkar

IIT Madras (India) - Electrical Engineering - Venkatesh Ramaiyan

Duration: 2012 - 2014

See also: <http://www-sop.inria.fr/members/Eitan.Altman/Ganesh/Home.html>

This project aims at producing outstanding contributions to the foundations of the theory of networks, in game theory, team theory, optimization and analysis. Three areas in networking will be used to apply these: (i) economy of networks and network neutrality, (2) scheduling in wireless networks, and (3) distributed optimization issues in ad-hoc networks.

### 8.3.2. Inria International Partners

#### 8.3.2.1. 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 Palermo (Italy), and Univ. of Twente (The Netherlands); Petrozavodsk State Univ. (Russia); Ghent Univ. (Belgium); see Sections 8.4.1.1 and 8.4.2.

### 8.3.3. Participation In other International Programs

E. Altman, I. Brunetti, M. Haddad, G. Neglia, A. Reiffers and J. K. Sreedharan participated in the CEFIPRA workshop on "New Avenues for Network Models" (13-15 January 2014) and the IFCAM workshop on Social Networks (16 January 2014). CEFIPRA and IFCAM organized these workshops to celebrate 6 years of successful collaboration between Inria and Indian institutions. The travel and accommodation expenses were supported by CEFIPRA and IFCAM.

## 8.4. International Research Visitors

### 8.4.1. Visits of International Scientists

#### 8.4.1.1. Professors / Researchers

Vivek Borkar

Date: 17 November 2014 - 6 December 2014

Institution: IIT Bombay (India)

Pavel Chebotarev

Date: 19-26 September 2014

Institution: RAS Institute of Control Problems (Russia)

Mohamed Shaheen ElGamel

Date: 7-10 October 2014

Institution: AAST Alexandria (Egypt)

Fabio Fagnani

Date: 28-31 January 2014

Institution: Politecnico di Torino (Italy)

Daniel Figueiredo

Date: 20-29 November 2014

Institution: Univ. Federal do Rio de Janeiro (Brasil)

Anurag Kumar

Date: 27 May 2014 - 4 June 2014

Institution: IISc Bangalore (India)

Joy Kuri

Date: 18-24 May 2014

Institution: IISc Bangalore (India)

Evsey Morozov

Date: 20-24 October 2014

Institution: Petrozavodsk State Univ. (Russia)

Alexey Piunovskiy

Date: 19-24 May 2014

Institution: Univ. of Liverpool (UK)

Shanmugasundaram Ravikumar

Date: 25-30 April 2014

Institution: Google (USA)

Bruno Ribeiro

Date: 6-15 July 2014, 24-28 November 2014

Institution: Carnegie Mellon Univ. (USA)

Rajesh Sundaresan

Date: 17 November 2014 - 6 December 2014

Institution: IISc Bangalore (India)

Don Towsley

Date: 18-21 February 2014

Institution: Univ. of Massachusetts, Amherst (USA)

Sulan Wong

Date: 9 December 2013 - 15 January 2014

Institution: Univ. of A Coruña (Spain)

Uri Yechiali

Date: 21 April 2014 - 4 May 2014

Institution: Tel Aviv Univ. (Israel)

Yi Zhang

Date: 19-24 May 2014

Institution: Univ. of Liverpool (UK)

#### 8.4.1.2. *Ph.D. students*

Giuseppe Di Bella

Date: 1 May 2014 - 30 September 2014

Institution: Univ. of Palermo (Italy)

Arnob Ghosh

Date: 1 June 2014 - 31 August 2014

Institution: Univ. of Pennsylvania (USA)

Cristina Rottondi

Date: 1 April 2014 - 30 May 2014

Institution: Politecnico di Milano (Italy)

#### 8.4.1.3. *Internships*

Aditya Aradhya

Date: 9 June 2014 - 11 July 2014

Institution: Madras Univ. (India)

Dalel Khalladi

Date: 1 March 2014 - 31 August 2014

Institution: Univ. Avignon (France)

Najmeddine Majed

Date: 1 May 2014 - 31 October 2014

Institution: SupCom Tunis (Tunisia)

Nedko Nedkov

Date: 1 April 2014 - 31 July 2014

Institution: National and Kapodistrian Univ. of Athens (Greece)

Shanay Shah

Date: 15 May 2014 - 14 July 2014

Institution: IIT Bombay (India)

Anastasiia Varava

Date: 1 March 2014 - 31 August 2014

Institution: Univ. of Nice Sophia Antipolis (France)

### 8.4.2. *Visits to International Teams*

#### 8.4.2.1. *Research stays abroad*

MAESTRO members have visited (the)

- Create-Net, Italy in the period 14-19 April 2014 (**A. Reiffers**);
- Eurandom, The Netherlands in the period 20-24 January 2014 (**K. Avrachenkov**);
- Federal Univ. Of Rio de Janeiro, Brazil in the periods 30 July - 5 August 2014 (**E. Altman**) and 21-31 August 2014 (**G. Neglia** and **A. Reiffers**);
- Ghent Univ., Belgium in the period 15-16 December 2014 (**K. Avrachenkov**);
- Indian Institute of Science and Indian Institute of Technology (Mumbai), India in the period 11-23 January 2014 (**E. Altman**);
- National Univ. of Rosario, Argentina in the period 29 November - 16 December 2014 (**A. Jean-Marie**);
- Technion - Israel Institute of Technology, Tel Aviv, Israel in the periods 2-16 February 2014, 19 April - 3 May 2014 and 15-24 October 2014 (**E. Altman**) and 20 October - 17 December 2014 (**A. Reiffers**);
- Univ. of Bamberg, Germany in the period 19-21 March 2014 (**K. Avrachenkov**);
- Univ. of Delft, The Netherlands in the period 12-14 October 2014 (**E. Altman**);
- Univ. of Florence, Italy in the periods 14-18 July 2014 and 10-13 November 2014 (**G. Neglia**);
- Univ. of Illinois at Urbana-Champaign, USA in the period 1 October 2013 - 31 January 2014 (**M. El Chamie**);
- Univ. of Liverpool, UK in the period 30 March - 3 April 2014 (**K. Avrachenkov**);
- Univ. of Massachusetts at Amherst, USA in the periods 15 April – 16 May 2014 (**P. Nain**);
- Univ. of Waterloo, Canada in the period 16-19 July 2014 (**E. Altman**).

## 9. Dissemination

### 9.1. Promoting Scientific Activities

#### 9.1.1. Scientific events organisation

##### 9.1.1.1. General chair, scientific chair

- 7th Intl. Conference on Network Games, Control and Optimization (NETGCOOP 2014, Trento, Italy) (**E. Altman** as steering committee chair);
- 8th Intl. Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS 2014, Bratislava, Slovakia) (**E. Altman** as steering committee co-chair);
- 2nd IEEE Intl. Workshop on Self-Organizing Networks (SONETS 2014, Istanbul, Turkey) (**M. Haddad** as workshop co-chair);
- 10ème Atelier en Evaluation de Performances (AEP10, Sophia Antipolis, France) (**S. Alouf** and **A. Jean-Marie**) [76].

##### 9.1.1.2. Member of the organizing committee

- 33rd IEEE Intl. Conference on Computer Communications (IEEE INFOCOM 2014, Toronto, Canada) (**G. Neglia** as publicity chair);
- 32nd Intl. Symposium on Computer Performance, Modeling, Measurements and Evaluation (IFIP WG 7.3 Performance 2014, Turin, Italy) (**P. Nain** as steering committee member);
- 12th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt 2014, Hammamet, Tunisia) (**E. Altman** as steering committee member);
- 10ème Atelier en Evaluation de Performances (AEP10, Sophia Antipolis, France) (**J. K. Sreedharan**).

### 9.1.2. Scientific events selection

#### 9.1.2.1. Chair of the conference program committee

- 2nd IEEE Intl. Workshop on Self-Organizing Networks (SONETS 2014, Istanbul, Turkey) (**M. Haddad** as workshop co-chair);
- 12th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt 2014, Hammamet, Tunisia) (**M. Haddad** as co-PC chair).

#### 9.1.2.2. Member of the conference program committee (list in alphabetical order of event name)

- 9th ACM Workshop on Challenged Networks (CHANTS 2014, Maui, Hawaii, USA) (**G. Neglia**);
- 10th Advanced Intl. Conference on Telecommunications (AICT 2014, Paris, France) (**K. Avrachenkov**);
- 34th IEEE Intl. Conference on Computer Communications (IEEE INFOCOM 2015, Hong Kong) (**G. Neglia**);
- 6th IEEE Intl. Workshop on Network Science for Communication Networks (IEEE NetSciCom 2014, Toronto, Canada) (**K. Avrachenkov, G. Neglia**);
- IEEE Multi-Conference on Systems and Control (MSC 2014, Nice/Antibes, France) (**M. El Chamie**);
- 5th Intl. Conference on Access Networks (ACCESS 2015, Seville, Spain) (**K. Avrachenkov**);
- 8th Intl. Conference on Game Theory and Management (GTM 2014, St. Petersburg, Russia) (**E. Altman**);
- 7th Intl. Conference on Network Games, Control and Optimization (NETGCOOP 2014, Trento, Italy) (**K. Avrachenkov, M. Haddad**);
- 5th Intl. Conference on Next Generation Networks and Services (NGNS 2014, Casablanca, Morocco) (**M. Haddad**);
- 14th Intl. Conference on Next Generation Wired/Wireless Networking (NEW2AN 2014, St. Petersburg, Russia) (**K. Avrachenkov**);
- 8th Intl. Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS 2014, Bratislava, Slovakia) (**S. Alouf, K. Avrachenkov, M. Haddad, G. Neglia**);
- 29th Intl. Symposium on Computer and Information Sciences (ISCIS 2014, Krakow, Poland) (**A. Jean-Marie**);
- 32nd Intl. Symposium on Computer Performance, Modeling, Measurements and Evaluation (IFIP WG 7.3 Performance 2014, Turin, Italy) (**S. Alouf**);
- 16th Intl. Symposium of Dynamic Games (ISDG 2014, Amsterdam, The Netherlands) (**E. Altman**);
- 7th Intl. Workshop on Multiple Access Communications (MACOM 2014, Halmstad, Sweden) (**K. Avrachenkov**);
- Networking and Electronic Commerce Research Conference (NAEC 2014, Trieste, Italy) (**E. Altman**);
- 1st Symposium on the Control of Network Systems (SCONES 2014, Boston, Massachusetts, USA) (**E. Altman**);
- 11th Workshop on Algorithms and Models for the Web Graph (WAW 2014, Beijing, China) (**K. Avrachenkov**);
- Workshop on Cooperative and Cognitive Networks (Nicosia, Cyprus) (**M. Haddad**);
- 16th Workshop on Mathematical Performance Modeling and Analysis (MAMA 2014, Austin, Texas, USA) (**A. Jean-Marie, P. Nain**).

### 9.1.3. Journal

#### 9.1.3.1. Editor-in-chief

- *Performance Evaluation* (PEVA) (**P. Nain** since 1 January 2008).

#### 9.1.3.2. Member of the editorial board (list in alphabetical order of journal name)

- *Dynamic Games and Applications* (DGAA) (**E. Altman** since 2011);
- *Elsevier Computer Communications* (COMCOM) (**G. Neglia** since 2014);
- *IEEE Transaction on Control of Networks* (TCNS) (**E. Altman** since 2013);
- *IEEE/ACM Transaction on Networking* (ToN) (**E. Altman** since 2013);
- *Journal of Economic Dynamics and Control* (JEDC) (**E. Altman** since 2001);
- *Performance Evaluation* (PEVA) (**K. Avrachenkov** since 2008).

#### 9.1.3.3. Reviewer (list in alphabetical order of journal name)

- *Computer Communications* (COMCOM) (**S. Alouf, G. Neglia**);
- *Computer Networks* (COMNET) (**E. Altman, K. Avrachenkov, A. Dandoush, I. Dimitriou, G. Neglia**);
- *Elsevier Ad Hoc Networks* (ADHOC) (**G. Neglia**);
- *EURASIP Journal on Wireless Communications and Networking* (JWCN) (**M. Haddad**);
- *IEEE Communications Magazine* (COMMAG) (**M. Haddad**);
- *IEEE Journal on Selected Areas in Communications* (JSAC) (**M. Haddad**);
- *IEEE Trans. on Automatic Control* (TAC) (**G. Neglia**);
- *IEEE Trans. on Communications* (TCOM) (**M. Haddad**);
- *IEEE Trans. on Neural Networks and Learning Systems* (TNNLS) (**G. Neglia**);
- *IEEE Trans. on Parallel and Distributed Systems* (TPDS) (**G. Neglia**);
- *IEEE Trans. on Vehicular Technology* (TVT) (**M. Haddad**);
- *IEEE Trans. on Wireless Communications* (TWC) (**M. Haddad**);
- *Performance Evaluation* (PEVA) (**G. Neglia**).

#### 9.1.4. Leadership within the scientific community

- E. Altman is a fellow member of IEEE (Class of 2010). The society of dynamic games attributes in July 2014 the Isaacs Award to E. Altman for his research on game theory. (Award attributed once every two years.)
- E. Altman, A. Jean-Marie and P. Nain are (elected) members of IFIP WG7.3 on “Computer System Modeling”.
- P. Nain has been the vice-Chair of the IFIP WG7.3 working group on “Computer System Modeling” (from 30 June 2007 to 21 July 2014).

#### 9.1.5. 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.”
- is Scientific coordinator of the European project CONGAS.

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 in the Scientific Board of the Univ. of Montpellier 2, at the Scientific Council of the Doctoral School “Sciences and Agrosiences” of the Univ. of Avignon, at the Regional Conference of Research Organisms (CODOR), at the Regional Consulting Committee for Research and Technological Development (ARAGO Committee);
- was member of the managing sub-committee of the Project-Team Committee of the Inria Sophia Antipolis – Méditerranée research center (July 2010 – August 2014);
- is a member of the Steering Committee of the GDR RO, a national research initiative on Operations Research sponsored by the CNRS;
- is president of the Technical and Industrial Orientation Council for Information Technologies (COSTI TIC) of the Transferts LR association (since 2009);
- is Head of project-team MAESTRO since October 2014.

P. Nain

- is Chairman of Inria’s Evaluation Committee since 1 September 2012 (<http://www.inria.fr/en/institute/organisation/committees/evaluation-committee>); as part of this duty he has presided the 2014 recruitment committees for senior Inria researchers (DR2, DR1) and for junior Inria researchers (CR1).
- was Head of project-team MAESTRO (September 2003 – September 2014).

G. Neglia

- is the scientific delegate for European partnerships for Inria Sophia Antipolis – Méditerranée;
- was member of the recruitment committee for a *Maître de Conférences* position at Univ. of Avignon.

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

- CC (Comité de Centre): General Information Commission (**G. Neglia** since September 2013);
- CSD: Doctoral Committee (**S. Alouf**, since February 2006);
- NICE: Invited Researchers Committee (**K. Avrachenkov**, since 2010);

and in charge of the following tasks for the research center:

- Supervision and validation of the project-teams’ yearly activity reports (**K. Avrachenkov**, since 2010);
- Accounting for the monthly Project-Team Committee meetings (**S. Alouf**, February 2012 – August 2014);
- Organizing MAESTRO internal meetings (**J. K. Sreedharan**, since November 2013).

## 9.2. Teaching - Supervision - Juries

### 9.2.1. Teaching

Licence:

S. Alouf, “Probability”, 38.5H, 1st year Water Engineering degree (L3), Univ. of Nice Sophia Antipolis (UNS), France.

M. El Chamie, “Mathematics”, 18H, Miage (L3), UNS, France.

M. El Chamie, “Networks”, 22H, Computer Science Program (L3), UNS, France.

M. El Chamie, “Programmation Web - Aspect Serveur”, 16.5H, Computer Science Program (L1), UNS, France.

G. Neglia, “Statistics”, 14H, 1st year Water Engineering degree (L3), UNS, France.



## Master:

- S. Alouf, “Performance Evaluation of Networks”, 31.5H, M2 IFI Ubinet, UNS, France.  
 M. El Chamie, “Réseaux Couches Basses”, 13.5H, M1 Miage, UNS, France.  
 M. Haddad, “Information theory”, 16H, M1, Univ. of Avignon, France.  
 G. Neglia, “Performance Evaluation of Networks”, 31.5H, M2 IFI Ubinet, UNS, France.  
 G. Neglia, responsible for the “Winter School on Complex Networks”, 42H, M1 Computer Science, UNS, France.

## Doctorat:

- A. Jean-Marie, “Advanced Markov Modeling”, 18H, Univ. of Montpellier 2, France.

**9.2.2. Supervision**

## PhD:

- Nicaise Choungmo Fofack, “On Models for Performance Analysis of a Core Cache Network and Power Save of a Wireless Access Network” [10], Univ. of Nice Sophia Antipolis (UNS), 21 February 2014, Advisors: Sara Alouf and Philippe Nain.  
 Mahmoud El Chamie, “Optimization, Control, and Game Theoretical Problems in Consensus Protocols” [11], Univ. of Nice Sophia Antipolis (UNS), 21 November 2014, Advisors: Konstantin Avrachenkov and Giovanni Neglia.  
 Julien Gaillard, “Recommendation Systems: Dynamic Adaptation and Argumentation”, Univ. of Avignon et Pays du Vaucluse (UAPV), 10 December 2014, Advisors: Eitan Altman, Marc El-Beze and Emmanuel Ethis.  
 Olivia Morad, “Prefetching Control for On-Demand Contents Distribution: A Markov Decision Process Study”, Univ. of Montpellier 2, 17 September 2014, Advisor: Alain Jean-Marie.  
 Marina Sokol, “Clustering and learning techniques for traffic/user classification” [12], Univ. of Nice Sophia Antipolis (UNS), 29 April 2014, Advisors: Paulo Gonçalves (Inria project-team DANTE) and Philippe Nain.

## PhD in progress:

- Alberto Benegiamo, “Mathematical tools for smart grids,” 1 November 2013, advisors: Patrick Loiseau (Eurecom) and Giovanni Neglia.  
 Ilaria Brunetti, “Cooperative and competitive content dissemination in social networks,” 1 October 2012, advisor: Eitan Altman.  
 Arun Kadavankandy, “Random Matrix Theory and Complex Networks,” 5 March 2014, advisors: Konstantin Avrachenkov and Laura Cottatellucci (Eurecom).  
 Jithin Kazhuthuveetil Sreedharan, “Diffusion processes in complex networks,” 23 July 2013, advisor: Konstantin Avrachenkov.  
 Hlib Mykhailenko, “Probabilistic approaches for big data analysis,” 1 May 2014, advisors: Fabrice Huet (SCALE team) and Philippe Nain.  
 Yonathan Portilla, “Analysis of social networks,” 1 January 2012, advisor: Eitan Altman.  
 Alexandre Reiffers, “Modelling competition and cooperation in telecommunication networks,” 15 October 2012, advisor: Eitan Altman.  
 Abdoulaye Tall, “Self organisation in wireless networks,” 1 December 2012, advisors: Eitan Altman and Zwi Altman (Orange Labs).

**9.2.3. Juries**

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

- Marceau Coupechoux: 26 May 2014, Telecom ParisTech, (E. Altman as examiner);

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

- Nicaise Choungmo Fofack: 21 February 2014, Inria, Sophia Antipolis (**S. Alouf** and **P. Nain** as advisors, **G. Neglia** as invited member);
- Mahmoud El Chamie: 21 November 2014, Inria, Sophia Antipolis (**K. Avrachenkov** and **G. Neglia** as advisors);
- Dariush Fooladivanda: 18 July 2014, Univ. of Waterloo (**E. Altman** as reviewer);
- Julien Gaillard: 10 December 2014, Univ. of Avignon (**E. Altman** as advisor);
- Arnob Ghosh: 16 December 2014, Univ. of Pennsylvania (**E. Altman** as examiner);
- Stefano Iellamo: 4 December 2014, Telecom ParisTech (**E. Altman** as examiner);
- Benjamin Larrousse: 11 December 2014, Univ. Paris Sud (**E. Altman** as examiner);
- Olivia Morad: 17 September 2014, Univ. of Montpellier 2 (**A. Jean-Marie** as advisor);
- Renaud Sallantin: 29 September 2014, IRT Toulouse (**K. Avrachenkov** as reviewer);
- Tatiana Seregina: 18 November 2014, LAAS, Toulouse (**K. Avrachenkov** as reviewer);
- Marina Sokol: 29 April 2014, Inria, Sophia Antipolis (**P. Nain** as advisor);

### 9.3. Popularization

S. Alouf is a member of MASTIC, a commission in charge of popularization and regional and internal scientific animation (since November 2011).

### 9.4. Participation in scientific events

#### 9.4.1. Keynotes, tutorials and invited talks

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

- *Analysis of competition and visibility in complex networks*, at WPerformance 2014 workshop, in conjunction with the XXXIV Brazilian Conference of Computer Science (CSBC), Brasilia, Brazil, 29 July 2014 (**E. Altman**);
- *Timelines Analysis and competition over popularity, influence and visibility in social networks*, at 32nd Intl. Symposium on Computer Performance, Modeling, Measurements, and Evaluation (Performance), Turin, Italy, 9 October 2014 (**E. Altman**),

the following tutorials (in alphabetical order):

- *Introduction to Complex Networks*, at Winter School on “Complex Networks”, Sophia Antipolis, 27-31 January 2014 (**G. Neglia**);
- *Network Formation Games*, at Advanced Research Center, Campione d’Italia, Italy, 8-11 September 2014 (**K. Avrachenkov**);
- *On competition in social networks*, at CEFIPRA Workshop on “New Avenues for Network Models”, Bangalore, India, 13-15 January 2014 (**E. Altman**);
- *Random Walk Methods for Complex Networks*, at Winter school on “Complex Networks”, Sophia Antipolis, 27-31 January 2014 (**K. Avrachenkov**);
- *Random Walk Methods for Complex Networks*, at Summer school ResCom on “Complex Networks”, Corsica, 13-17 May 2014 (**K. Avrachenkov**),

and the following invited talks (in alphabetical order):

- *Analysis of competition and visibility in complex networks*, Federal Univ. of Rio de Janeiro, Brazil, 1 August 2014 (**E. Altman**);
- *Competition over visibility on Online Social Networks*, Create-Net, Italy, 15 April 2014, (**A. Reiffers**);
- *Distribution and Dependence of Extremes in Network Sampling Processes*, at Vilnius Probability Conference, Lithuania, 3 July 2014 (**K. Avrachenkov**);
- *Energy-Efficient Resource Management Games in Wireless Networks*, at CEFIPRA Workshop, IISc Bangalore, India, 15 January 2014 (**M. Haddad**);
- *Game Theory Applied to Advertising Competition in Online Social Networks*, Federal Univ. of Rio de Janeiro, Brazil, 29 August 2014 (**A. Reiffers**);
- *Graph-based Semi-supervised Methods for Community Detection*, at EURANDOM Workshop, The Netherlands, 22 January 2014 (**K. Avrachenkov**);
- *How to network in online social networks*, at IFCAM Workshop, IISc Bangalore, India, 16 January 2014 (**G. Neglia**);
- *Routing Games Applied to Online Social Networks*, Technion - Israel Institute of Technology, Israel, 10 December 2014 (**A. Reiffers**);
- *Teletraffic Engineering for Smart Grids*, Federal Univ. of Rio de Janeiro, Brazil, 23 August 2014 (**G. Neglia**);
- *Teletraffic Engineering for Smart Grids*, Univ. of Florence, Italy, 15 July 2014 (**G. Neglia**);
- *Weight Selection in Consensus Protocols*, Chalmers Univ. of Technology, 23 October 2014 (**M. El Chamie**).

#### 9.4.2. Conferences and workshops

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

- American Control Conference (ACC), 4-6 June 2014, Portland, Oregon, USA (**M. El Chamie**);
- 53rd IEEE Conference on Decision and Control (CDC), 15-17 December 2014, Los Angeles, California, USA (**M. El Chamie, G. Neglia**);
- 33rd IEEE Intl. Conf. on Computer Communications (INFOCOM), 27 April - 2 May 2014, Toronto, Canada (**M. Haddad**);
- IEEE Infocom Workshop on Network Science for Communication Networks (NetSciCom), 2 May 2014, Toronto, Canada (**G. Neglia**);
- IEEE Infocom Workshop on Communications and Control for Smart Energy Systems (CCSES), 28 April 2014, Toronto, Canada (**G. Neglia**);
- IEEE Intl. Conference on Communications (ICC), 10-14 June 2014, Sydney, Australia (**G. Neglia**);
- 13th IFIP Intl. Conf. on Networking (Networking), 2-4 June 2014, Trondheim, Norway (**A. Reiffers**);
- IFIP Performance, 7-9 October 2014, Turin, Italy (**M. Haddad**);
- 7th Intl. Conference on Network Games, Control and Optimization (NETGCOOP), 29-31 October 2014, Trento, Italy (**I. Brunetti, A. Reiffers**);
- 12th Intl. Symp. on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), 12-16 May 2014, Hammamet, Tunisia (**E. Altman, M. Haddad**);
- 29th Intl. Symposium on Computer and Information Sciences (ISCIS), 27-28 October 2014, Krakow, Poland (**A. Jean-Marie**);
- 3rd Intl. Workshop on IEEE Complex Networks and their Applications, 23-27 November 2014, Marrakech, Morocco (**J. K. Sreedharan**);
- Intl. Workshop on Modeling, Analysis and Management of Social Networks and their Applications (SOCNET), 19 March 2014, Bamberg, Germany (**K. Avrachenkov**);
- Social Networking Workshop (in conjunction with COMSNETS 2014), 10 January 2014, Bangalore, India (**A. Reiffers**);
- 10ème Atelier en Evaluation de Performances (AEP), 11-13 June 2014, Sophia Antipolis (**M. El Chamie, J. K. Sreedharan**).

### 9.4.3. Schools and doctoral courses

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

- Doctoral course on “Advanced Game Theory” (20H), 12-27 May 2014, Montpellier (**I. Brunetti**);
- Doctoral course on “Advanced Markov Modeling” (20H), 18-28 February 2014, Montpellier (**I. Brunetti, A. Reiffers**);
- EIT ICT Labs summer school on “Smart Energy” (120H), 18-29 August 2014, Stockholm (KTH Royal Institute of Technology, first week) and Karlsruhe (Karlsruhe Institute of Technology, second week) (**A. Benegiamo**);
- Grid5000 spring school 2014 (18H), 17-19 June 2014, Lyon (**H. Mykhailenko**);
- ResCom summer school on “Complex Networks” (30H), 13-17 May 2014, Corsica (**A. Kadvankandy, J. K. Sreedharan**);
- School on “Game Theory for Telecommunications” (56H), 8-11 September 2014, Advanced Research Center, Campione d’Italia, Italy (**V. Singh**);
- Winter School on “Complex Networks” (30H), 27-31 January 2014, Sophia Antipolis (**A. Benegiamo, J. K. Sreedharan**).

## 10. Bibliography

### Major publications by the team in recent years

- [1] U. G. ACER, P. GIACCONE, D. HAY, G. NEGLIA, S. TARAPIAH. *Timely Data Delivery in a Realistic Bus Network*, in "IEEE Transactions on Vehicular Technology", March 2012, vol. 61, n<sup>o</sup> 3, pp. 1251–1265 [DOI : 10.1109/TVT.2011.2179072], <http://hal.inria.fr/hal-00759357>
- [2] S. ALOUF, V. MANCUSO, N. CHOUNGMO FOFACK. *Analysis of power saving and its impact on web traffic in cellular networks with continuous connectivity*, in "Pervasive and Mobile Computing", October 2012, vol. 8, n<sup>o</sup> 5, pp. 646-661 [DOI : 10.1016/J.PMCI.2012.04.001], <http://hal.inria.fr/hal-00729082>
- [3] E. ALTMAN, T. BAŞAR, F. DE PELLEGRINI. *Optimal Control in Two-Hop Relay Routing*, in "IEEE Transactions on Automatic Control", March 2011, vol. 56, n<sup>o</sup> 3, pp. 670-675, <http://dx.doi.org/10.1109/TAC.2010.2095930>
- [4] E. ALTMAN, P. NAIN, J.-C. BERMOND. *Distributed Storage Management of Evolving Files in Delay Tolerant Ad Hoc Networks*, in "Proc. of IEEE INFOCOM 2009", Rio de Janeiro, Brazil, April 2009, pp. 1431-1439, <http://dx.doi.org/10.1109/INFCOM.2009.5062059>
- [5] E. ALTMAN, P. NAIN, A. SHWARTZ, Y. XU. *Predicting the Impact of Measures Against P2P Networks on the Transient Behaviors*, in "Proc. of IEEE INFOCOM 2011", Shanghai, China, April 2011, pp. 1440-1448, <http://dx.doi.org/10.1109/INFCOM.2011.5934931>
- [6] E. ALTMAN, F. DE PELLEGRINI. *Forward correction and fountain codes in delay-tolerant networks*, in "IEEE/ACM Transactions on Networking", February 2011, vol. 19, n<sup>o</sup> 1, pp. 1-13, <http://dx.doi.org/10.1109/TNET.2010.2091968>
- [7] K. AVRACHENKOV, J. A. FILAR, P. HOWLETT. *Analytic Perturbation Theory and Its Applications*, SIAM, December 2013, 372 p. [DOI : 10.1137/1.9781611973143], <http://hal.inria.fr/hal-00926397>

- [8] K. AVRACHENKOV, B. RIBEIRO, D. TOWSLEY. *Improving Random Walk Estimation Accuracy with Uniform Restarts*, in "Proc. of 7th Workshop on Algorithms and Models for the Web Graph (WAW 2010)", Stanford University, CA, USA, Lecture Notes in Computer Science, December 2010, vol. 6516, pp. 98-109, [http://dx.doi.org/10.1007/978-3-642-18009-5\\_10](http://dx.doi.org/10.1007/978-3-642-18009-5_10)
- [9] X. ZHANG, G. NEGLIA, J. KUROSE, D. TOWSLEY. *Performance Modeling of Epidemic Routing*, in "Elsevier Computer Networks", July 2007, vol. 51, n<sup>o</sup> 10, pp. 2867-2891, <http://dx.doi.org/10.1016/j.comnet.2006.11.028>

## Publications of the year

### Doctoral Dissertations and Habilitation Theses

- [10] N. É. CHOUNGMO FOFACK. *On models for performance analysis of a core cache network and power save of a wireless access network*, Université Nice Sophia Antipolis, February 2014, <https://tel.archives-ouvertes.fr/tel-00968894>
- [11] M. EL CHAMIE. *Optimization, Control, and Game Theoretical Problems in Consensus Protocols*, Université Nice Sophia Antipolis, November 2014, <https://hal.inria.fr/tel-01103939>
- [12] M. SOKOL. *Graph-based semi-supervised learning methods and quick detection of central nodes*, Université Nice Sophia Antipolis, April 2014, <https://tel.archives-ouvertes.fr/tel-00998394>

### Articles in International Peer-Reviewed Journals

- [13] E. ALTMAN. *Bio-Inspired Paradigms in Network Engineering Games*, in "Journal of Dynamics and Games (JDG)", January 2014, vol. 1, n<sup>o</sup> 1, pp. 1-15 [DOI : 10.3934/JDG.2014.1.1], <https://hal.inria.fr/hal-00918809>
- [14] E. ALTMAN, M. K. HANAWAL, R. SUNDARESAN. *Regulation of Off-Network Pricing in a Nonneutral Network*, in "ACM Transactions on Internet Technology", October 2014, vol. 14, n<sup>o</sup> 2-3, 21 p. [DOI : 10.1145/2663491], <https://hal.archives-ouvertes.fr/hal-01087475>
- [15] K. AVRACHENKOV, L. COTTATELLUCCI, L. MAGGI. *Confidence Intervals for the Shapley–Shubik Power Index in Markovian Games*, in "Dynamic Games and Applications", March 2014, vol. 4, n<sup>o</sup> 1, pp. 10-31 [DOI : 10.1007/s13235-013-0079-6], <https://hal.inria.fr/hal-01092383>
- [16] K. AVRACHENKOV, A. ESHRAGH, J. A. FILAR. *On transition matrices of Markov chains corresponding to Hamiltonian cycles*, in "Annals of Operations Research", June 2014, 17 p. [DOI : 10.1007/s10479-014-1642-2], <https://hal.inria.fr/hal-01092355>
- [17] K. AVRACHENKOV, O. HABACHI, A. PIUNOVSKIY, Y. ZHANG. *Infinite horizon optimal impulsive control with applications to Internet congestion control*, in "International Journal of Control", December 2014, 14 p. [DOI : 10.1080/00207179.2014.971436], <https://hal.inria.fr/hal-01092363>
- [18] K. AVRACHENKOV, N. LITVAK, M. SOKOL, D. TOWSLEY. *Quick Detection of Nodes with Large Degrees*, in "Internet Mathematics", May 2014, vol. 10, n<sup>o</sup> 1-2, pp. 1-19 [DOI : 10.1080/15427951.2013.798601], <https://hal.inria.fr/hal-01092304>

- [19] K. AVRACHENKOV, E. MOROZOV. *Stability analysis of GI/GI/c/K retrial queue with constant retrial rate*, in "Mathematical Methods of Operations Research", June 2014, vol. 79, n<sup>o</sup> 3, pp. 273-291 [DOI : 10.1007/s00186-014-0463-Z], <https://hal.inria.fr/hal-01092394>
- [20] K. AVRACHENKOV, E. MOROZOV, R. NEKRASOVA, B. STEYAERT. *Stability Analysis and Simulation of N-class Retrial System with Constant Retrial Rates and Poisson Inputs*, in "Asia-Pacific Journal of Operational Research", May 2014, vol. 31, n<sup>o</sup> 02, 18 p. [DOI : 10.1142/S0217595914400028], <https://hal.inria.fr/hal-01092341>
- [21] K. AVRACHENKOV, P. NAIN, U. YECHIALI. *A retrial system with two input streams and two orbit queues*, in "Queueing Systems", May 2014, vol. 77, n<sup>o</sup> 1, pp. 1-31 [DOI : 10.1007/s11134-013-9372-8], <https://hal.inria.fr/hal-01092322>
- [22] N. CHOUNGMO FOFACK, P. NAIN, G. NEGLIA, D. TOWSLEY. *Performance evaluation of hierarchical TTL-based cache networks*, in "Computer Networks", June 2014, vol. 65, pp. 212-231 [DOI : 10.1016/J.COMNET.2014.03.006], <https://hal.inria.fr/hal-01094694>
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- [31] P. WIECEK, E. ALTMAN. *Stationary Anonymous Sequential Games with Undiscounted Rewards*, in "Journal of Optimization Theory and Applications", September 2014, pp. 1-25 [DOI : 10.1007/s10957-014-0649-9], <https://hal.inria.fr/hal-00947313>
- [32] Y. XU, E. ALTMAN, R. EL-AZOUZI, M. HADDAD, S.-E. ELAYOUBI, T. JIMENEZ. *Analysis of Buffer Starvation With Application to Objective QoE Optimization of Streaming Services*, in "IEEE Transactions on Multimedia", 2014, vol. 16, n<sup>o</sup> 3, pp. 813-827 [DOI : 10.1109/TMM.2014.2300041], <https://hal.inria.fr/hal-01005726>

### Invited Conferences

- [33] R. EL-AZOUZI, E. ALTMAN, I. BRUNETTI, M. HADDAD. *Cooperation in Groups: An Evolutionary Games Approach*, in "52nd Annual Allerton Conference on Communication, Control, and Computing", Monticello, United States, October 2014, <https://hal.inria.fr/hal-01107437>
- [34] R.-A. VACA-RAMIREZ, J. S. THOMPSON, E. ALTMAN, V.-M. RAMOS-RAMOS. *A game theory framework for a distributed and energy efficient bandwidth expansion process*, in "1st IEEE INFOCOM International Workshop on Green Cognitive Communications and Computer Networking (GCCCN)", Toronto, Canada, April 2014, pp. 712 - 717 [DOI : 10.1109/INFCOMW.2014.6849318], <https://hal.inria.fr/hal-01101217>

### International Conferences with Proceedings

- [35] G. ACCONGIAGIOCO, E. ALTMAN, E. GREGORI, L. LENZINI. *A Game Theoretical study of Peering vs Transit in the Internet*, in "6th IEEE INFOCOM International Workshop on Network Science for Communication Networks (NetSciCom)", Toronto, Canada, April 2014, pp. 783-788 [DOI : 10.1109/INFCOMW.2014.6849330], <https://hal.inria.fr/hal-00950851>
- [36] G. ACCONGIAGIOCO, E. ALTMAN, E. GREGORI, L. LENZINI. *Peering vs Transit: a Game Theoretical model for Autonomous Systems connectivity*, in "IFIP Networking Conference (Networking 2014)", Trondheim, Norway, June 2014, pp. 323-331 [DOI : 10.1109/IFIPNETWORKING.2014.6857114], <https://hal.inria.fr/hal-01006204>
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- [38] E. ALTMAN, A. AVRITZER, R. EL-AZOUZI, L. PFLEGER DE AGUIAR, D. S. MENASCHE. *Rejuvenation and the Spread of Epidemics in General Topologies*, in "6th International Workshop on Software Aging and Rejuvenation (WoSAR)", Naples, Italy, November 2014, <https://hal.inria.fr/hal-01087263>
- [39] E. ALTMAN, J. KURI, R. EL-AZOUZI. *A routing game in networks with lossy links*, in "7th International Conference on NETWORK Games COntrol and OPTimization (NETGCOOP)", Trento, Italy, October 2014, <https://hal.inria.fr/hal-01066453>
- [40] E. ALTMAN, Y. PORTILLA. *Social Networks: A Cradle of Globalized Culture in the Mediterranean Region*, in "International Conference on Advances in Social Networks Analysis and Mining (ICASNAM)", Hammamet, Tunisia, January 2015 [DOI : 10.2139/SSRN.2518683], <https://hal.inria.fr/hal-01091258>



- [41] E. ALTMAN, N. SHIMKIN. *Strategic Posting Times over a Shared Publication Medium*, in "7th International Conference on NETWORK Games CONTROL and OPTimization (NETGCOOP)", Trento, Italy, October 2014, <https://hal.inria.fr/hal-01067124>
- [42] E. ALTMAN, P. WIECEK. *Applications of Stationary Anonymous Sequential Games to Multiple Access Control in Wireless Communications*, in "International Workshop on Wireless Networks: Communication, Cooperation and Competition (WNC3)", Hammamet, Tunisia, May 2014, pp. 575-578 [DOI : 10.1109/WIOPT.2014.6850349], <https://hal.inria.fr/hal-01006107>
- [43] *Best Paper*  
K. AVRACHENKOV, P. BASU, G. NEGLIA, B. RIBEIRO, D. TOWSLEY. *Pay few, influence most: Online myopic network covering*, in "6th IEEE INFOCOM International Workshop on Network Science for Communication Networks (NetSciCom)", Toronto, Canada, May 2014, pp. 813-818 [DOI : 10.1109/INFCOMW.2014.6849335], <https://hal.inria.fr/hal-01092416>.
- [44] K. AVRACHENKOV, K. DE TURCK, D. FIEMS, B. PRABHU. *Information dissemination processes in directed social networks*, in "International Workshop on Modeling, Analysis and Management of Social Networks and their Applications (SOCNET)", Bamberg, Germany, March 2014, pp. 35-43, <https://hal.archives-ouvertes.fr/hal-00876873>
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- [54] M. EL CHAMIE, J. LIU, T. BAŞAR. *Design and Analysis of Distributed Averaging with Quantized Communication*, in "IEEE 53rd Annual Conference on Decision and Control (CDC)", Los Angeles, United States, December 2014, <https://hal.inria.fr/hal-01097688>
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