INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team MAESTRO

Models for Performance Analysis and Control of Networks

Sophia Antipolis - Méditerranée

Theme : Networks and Telecommunications

Table of contents

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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 in Avignon (E. Altman) and at LIRMM 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 the development of software tools for the performance evaluation of DEDS.

2.2. Highlights of the year

- Patents with ALCATEL-LUCENT BELL LABS on two mechanisms to control TCP flows individually [76], [77].
- New grant (two years) with Orange Labs on the modeling, performance evaluation and optimization of content-centric network architectures.
- A. Dandoush and A. Jean-Marie received the *Best Paper Award* of the Third International Conference on Communication Theory, Reliability, and Quality of Service (CTRQ2010; June 13, 2010, Athens, Greece) [28].
- Six papers have been accepted at the IEEE Infocom conference (April 10-15, 2011, Shanghai, China) [83], [94], [90], [89], [91], [84].

3. Scientific Foundations

3.1. Scientific Foundations

The main mathematical tools and formalisms used in MAESTRO include:

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

4. Application Domains

4.1. Application Domains

MAESTRO's main application area is networking and in particular, modeling, performance evaluation, optimization and control of protocols and network architectures. It includes:

- Internet infrastructure: TCP, high speed congestion control, voice over IP, service differentiation, quality of service;
- Internet applications: multicast, content distribution systems, peer-to-peer systems, overlay networks, multimedia traffic;
- 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.

5. Software

5.1. Web Graph Analyzer

Participants: Konstantin Avrachenkov, Danil Nemirovsky, Marina Sokol.

K. Avrachenkov, D. Nemirovsky and M. Sokol have continued to develop the software "Web Graph Analyzer" for the investigation of Web graph properties. With the help of the Web Graph Analyzer, one can study the local graph characteristics such as numbers and sets of incoming/outgoing links to/from a given page, the page level relative to a given root page, the global graph characteristics such as PageRank, Giant Strongly Connected Component and the number of dangling nodes. In 2010, the clustering module has been updated with new methods.

6. New Results

6.1. Congestion control and IP traffic characterization

Participants: Sara Alouf, Konstantin Avrachenkov, Alberto Blanc, Abdulhalim Dandoush, Alain Jean-Marie, Philippe Nain.

6.1.1. Estimating the round-trip time of long-lived TCP sessions

The Round-Trip Time (RTT) of a TCP connection represents an important characteristic whose knowledge is useful when controlling a long-lived flow at a router. In [44], K. Avrachenkov, S. Alouf, and P. Nain, in collaboration with D. Carra (Univ. Verona) and G. Post (ALCATEL-LUCENT BELL LABS), propose a passive, online RTT estimation methodology based on the traffic observed in one direction. The method uses spectral analysis along with a pattern-matching technique for the extraction of the fundamental frequency. Since the proposed solution estimates in real-time the RTT using one-way traffic, it represents a candidate for a possible implementation in routers.

This research is carried out within ADR "Semantic Networking" (see Section 7.1.1).

6.1.2. Flow-aware traffic management

The congestion control mechanism of TCP, while simple and scalable, has several well-known limitations: 1) often different flows experience synchronized losses leading to lower link utilization, and 2) when flows with different Round-Trip Times (RTT) share the same bottleneck link, flows with a smaller RTT receive a larger share of the capacity.

A. Blanc, K. Avrachenkov, and S. Alouf, in collaboration with G. Post (Alcatel-Lucent Bell Labs), propose a new flow-aware traffic management mechanism that aims at addressing the two aforementioned limitations, while being self-configuring and supporting different fairness criteria. The core idea of the proposed mechanism can be described as a two step process: 1) decide a target rate for each flow; 2) control each TCP flow in order to minimize the oscillations around the chosen target rate. We have proposed two mechanisms to control TCP flows individually. These two mechanisms, Monitor Rate and Binary Search are filed as patents [77], [76].

This research is carried out within ADR "Semantic Networking" (see Section 7.1.1).

6.1.3. Interaction between TCP and bottleneck buffer

K. Avrachenkov, A. Piunovskiy and Z. Yi (Univ. Liverpool) and U. Ayesta (BCAM, Spain) have studied the interaction between the AIMD (Additive Increase Multiplicative Decrease) [24] and MIMD (Multiplicative Increase Multiplicative Decrease) [32] congestion control and a bottleneck router with Drop Tail buffer. The problem is analyzed in the framework of deterministic hybrid models. The authors study conditions under which the system trajectories converge to limiting cycles with a single jump. Following that, they consider the problem of the optimal buffer sizing in the framework of multi-criteria optimization in which the Lagrange function corresponds to a linear combination of the average throughput and the average delay in the queue. Thus, a set of rules for optimal buffer sizing is established.

This research is carried out within ADR "Semantic Networking" (see Section 7.1.1).

6.1.4. Flow-level simulation of parallel downloads

Parallelism in the download process of large files is an efficient mechanism for distributed systems. In such systems, peers (clients) exploit the power of parallelism to download blocks of data stored in a distributed way over some other peers (servers). In [28], A. Dandoush and A. Jean-Marie investigate parallel downloading with capacity constraints. The basic problem is to predict the instantaneous bandwidth sharing that each client/server devotes to each data transfer flow. The authors propose and analyse a simple algorithm that works at the flow-level and uses the concept of "water-filling" (or min-max fairness). The response times of parallel downloading is analyzed (both distributions and averages) using the algorithm by flow level simulations. The results are compared to those of packet-level simulations after implementing the same process in the Network Simulator (ns-2).

6.2. Wireless communications

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Veeraruna Kavitha, Vincenzo Mancuso, Ricardo Masiero, Dorian Mazauric, Philippe Nain, Giovanni Neglia, Sreenath Ramanath, Alonso Silva, Saed Tarapiah, Acer Utku, Yuedong Xu.

6.2.1. Delay and disruption-tolerant networks (DTNs)

6.2.1.1. Single copy routing schemes

Forwarding decisions in routing protocols rely on information about the destination nodes provided by routing table states. When paths to a destination change, corresponding states become invalid and need to be refreshed with control messages for resilient routing. In large and highly dynamic networks, like DTNs, this overhead can crowd out the capacity for data traffic. In collaboration with S. Kalyanaraman (IBM Research, Bangalore) and A.A. Abouzeid (Resselaer Polytechnic Institute), U. Acer has proposed a new routing algorithm that is based on the concept of *weak state* [17]. This state is interpreted as a probabilistic hint, not as absolute truth. Weak state can remain valid without explicit messages, by systematically reducing the confidence in its accuracy. The packet is routed in the network according to the *random directional* walks, that are biased by the weak state at each node.

U. Acer, together with P. Drineas and A. Alhussein (Resselaer Polytechnic Institute), has also studied the notion of connectivity in topologies that vary with time and are represented by *time-graphs* [33]. In static graphs, it is well known that the network connectivity is tied to the spectral gap of the underlying adjacency matrix of the topology: if the gap is large, the network is well connected and a random walk on this graph has a small hitting time. For time-graphs, they have investigated a similar metric for time-graphs, which indicates how quickly opportunistic methods deliver packets to destinations, speed of convergence in estimating an entity, quickness in the online optimization of protocol parameters, etc. To this end, a time-graph is represented by a three-mode reachability tensor which allows them to check whether or not a vertex is reachable from another node within t steps. From an extensive set of simulations, they have concluded that the correlation between the expected hitting time of a random walk in the time-graph (following a non-homogenous Markov Chain) and the second singular value of the matrix obtained by unfolding the reachability tensor is significantly large (above 90%).

6.2.1.2. Adaptive epidemic routing in DTNs

G. Neglia and R. Masiero have explored a recently proposed optimization framework that relies on local sub-gradient methods and consensus algorithms. They have been able to extend existing convergence results in order to apply them to DTNs, under a general class of mobility processes with memory and asynchronous operation [79] [93].

In [18] S. Alouf and G. Neglia, together with A. Fialho (INRIA-MICROSOFT joint center, Orsay), I. Carreras and D. Miorandi (Create-Net, Italy) have proposed a framework to learn in a distributed and on-line way a good forwarding policy in delay tolerant networks. Validation was carried out via simulations for different generation time, mutation noise, and mutation variance. This research was described in Maestro 2008 activity report.

6.2.1.3. Routing in quasi-deterministic networks

U. Acer, G. Neglia and S. Tarapiah, together with P. Giaccon (Politecnico di Torino) and D. Hay (Columbia Univ.), have investigated routing in DTNs where the underlying node mobility is known in advance but can be modified by random effects. In [73] [81], they consider, as a case-study, a metropolitan DTN composed of WiFi-enabled buses and bus stops. They propose a simple stochastic model for bus arrivals at stops, supported by a study of real-life bus traces collected in Turin. A succinct graph representation of this model allows them to determine the route maximizing the delivery probability by a given deadline as an instance of a particular stochastic shortest path problem.

6.2.1.4. Network coding

Network coding is an efficient way to transfer packets. It is especially appealing for applications that need reliability but use channels that do not have feedback. In [38] E. Altman, in collaboration with F. De Pellegrini (Create-Net, Italy) and L. Sassatelli (I3S/Univ. Nice Sophia Antipolis), studies their performance in the context of DTNs when both memory (single buffer assumption) as well as energy resources are scarce. Another wireless framework that illustrates the advantage of using network coding is provided in [42]. There, E. Altman, in collaboration with a G. Bansal, V. Sharma and N. Mehta (all from IISc, Bangalore), shows the asymptotic optimality.

The theory of network coding shows that algebraic mixing of information within the network, can increase the network goodput while in the meantime reducing bandwidth and power consumption. G. Neglia and X. Zhang (Fordham Univ.) investigate in [80] the benefits of Random Linear Coding (RLC) for unicast communications in DTNs under epidemic routing. Their results confirm the potentiality of RLC, when there is only one flow and bandwidth is constrained, but show that for the case of concurrent multiple flows, RLC offers only slight improvement over the non-coded scenario unless both bandwidth and buffers are constrained.

6.2.1.5. Aging control in DTNs

The demand for Internet services that require frequent updates through small messages, also known as microblogging, has tremendously grown in the past few years. Although the use of such applications by domestic users is usually free, their access from mobile devices is subject to fees and consumes energy from limited batteries. When a user activates his mobile device and happens to be in the range of a service provider,

an update is received at the expense of monetary and energy costs. Thus, users face a tradeoff between costs and messages aging. In collaboration with R. El-Azouzi (LIA/Univ. Avignon) and D.S. Menasche (Univ. Massachusetts), E. Altman and Y. Xu investigate in [82] how to cope with such a tradeoff, by devising aging control policies. An aging control policy consists of deciding, based on the utility of the content, whether or not to activate the mobile device, and, if active, which technology to use (WiFi or 3G). They formulate a Markov decision process model that yields the optimal aging control policy. With this model, they show the existence of an optimal strategy in the class of threshold strategies. When the age of contents goes beyond a given threshold, users activate their mobile devices, and remain inactive otherwise. They further consider strategic content providers (publishers) that offer bonus packages to users, so as to incentivize them to download updates of advertisement campaigns. Two simple algorithms are presented for publishers to determine optimal bonus levels, leveraging the fact that users adopt their optimal aging control strategies. The accuracy of the model is validated against traces from the UMass DieselNet bus network.

6.2.2. Small cell networks

6.2.2.1. Interference limited multi-antenna

In [61], S. Ramanath, M. Debbah (Supelec), E. Altman and V. Kumar (Univ. Bangalore) address the following question: for a given interference level, how many users can be supported in a precoded, multi-antenna, small-cell network? They use tools from random matrix theory to derive the optimal number of users that can be supported for a given number of antennas at the base station and for a given interference level. Simulations establish the effectiveness of the asymptotic results in the finite regime.

6.2.2.2. Cell dimensioning

In [62], [67], S. Ramanath, V. Kavitha and E. Altman use tools from queueing theory to study the impact of mobility on the dimensioning of small cell networks. They derive optimal cell sizes which minimize key system metrics like expected waiting times, call blocking and drop probabilities, while considering different mobility profiles and classes of traffic.

The following observations were noted for one dimensional case [62]: a) the optimal cell size increases with the highest velocity, b) for a fixed power of transmission, there exists a limit velocity beyond which no useful communication occurs, c) the optimal cell sizes are insensitive to application.

An important (and dangerous) contrast that arises in 2D scenarios [67], in comparison with the 1D case, is the possibility of systems with very small values of drop/blocking probabilities but with almost zero useful transmission rates. Existence of such behavior is shown via the concept of average virtual server held up time. This possibility can be avoided by scaling both the power per transmission and the number of servers linearly with cell size, while obtaining the optimal cell size.

6.2.3. Ferry based local area networks

V. Kavitha and E. Altman have pursued their work on ferry based local area networks. These are static wireless networks (e.g. a sensor network) where packets are transmitted to and from nodes by a mobile vehicle (which can be a mobile base station). In [57] they study an opportunistic scheduling policy for a ferry operating in a fading environment. Mixed policies are considered for optimization, which define the probability with which a user is served given the radio condition of the user. Capacity maximizing as well as workload minimizing policies are considered and it is shown that the two policies would be different.

In [56] they consider a ferry operating in 'taxi' mode, i.e, it can stop at any point in its path when it encounters an active user. The fundamental theory of continuous polling systems is extended, analytical expressions for the expected virtual workload in the LAN are obtained and the workload expressions are used for optimizing the ferry trajectories.It is shown that by using two base stations, one can achieve fairness : the expected waiting times are independent of the positions of arrivals.

6.2.4. Massively dense ad hoc networks

A. Silva and E. Altman, together with H. Tembine and M. Debbah (both from Supelec), have pursued their work on the routing problems in static wireless ad-hoc networks in the continuum limit where the density of mobiles goes to infinity. Various outstanding researchers had proposed interdisciplinary approaches for solving this problem (using tools from either optics or electrostatics). In [64], [65], A. Silva and co-workers have found an important link between optimal transportation (a subject that has been made popular by the 2010 Fields Medal winner Cedric Villani) and wireless cellular networks. This new technique has further been proved to be useful to model the mobile association problem in very general settings.

In [63], A. Silva and E. Altman, in collaboration with G. Alfano and M. Debbah (both from Supelec), extend the routing problem to a setting where terminals are mobile. The results make use again of the theory of optimal transportation.

The pioneering work of A. Silva and E. Altman, in collaboration with P. Bernhard (COMORE, INRIA) and M. Debbah (Supelec), which had appeared in the proceedings of the Allerton conference and was reported in the 2007 MAESTRO activity report, has now appeared in an extended version as a journal paper in [22].

6.2.5. Analysis of base station consumption

In [92], V. Mancuso and S. Alouf discuss the various strategies that help reducing infrastructure costs, power costs, and greenhouse gas (GHG) emissions in cellular networks. In order to further shed light on the causes of energy waste in cellular networks, A. Chatzipapas, S. Alouf, and V. Mancuso have analyzed the power consumed at every different component of the base station. Then, based on the cost incurred in turning off the base station's power amplifiers, the study shows how to decide whether it is convenient to keep the base station idle during those intervals in which no traffic has to be sent, or to turn off the amplifiers. Finally, considering the impact of traffic statistics on the base station activity, V. Mancuso and S. Alouf have developed a queueing model with shared processor and repeated vacations to analyze the energy economy that a base station might achieve when adopting DRX/DTX-like power saving mechanisms. The model, both in case of Poisson arrivals or realistic http traffic, can be used to maximize the base station energy savings under a given set of traffic performance constraints.

6.2.6. Mesh networks

In [60], V. Mancuso, in collaboration with O. Gurewitz (Ben Gurion Univ.), A. Khattab (Univ. Louisiana) and E. W. Knightly (Rice Univ.), has tackled the problem of throughput unfairness for IEEE 802.11, via elastic rate limiting strategies to be implemented in a few selected network nodes. The research has been described in Maestro 2009 activity report.

The work by D. Mazauric, P. Nain, J-C. Bermond (MASCOTTE, INRIA) and V. Misra (Univ. Columbia) on "Distributed call scheduling" reported in the MAESTRO 2009 Activity Report (see section 6.2.1.2) was presented as a poster at ACM Sigmetrics 2010 [86].

6.3. Information systems

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Abdulhalim Dandoush, Alain Jean-Marie, Philippe Nain, Danil Nemirovsky, Sreenath Ramanath, Yuedong Xu.

6.3.1. Peer-to-peer networks

6.3.1.1. Content dissemination in P2P networks

In [85] and [84], E. Altman, P. Nain and Y. Xu, in collaboration with A. Shwartz (Technion), study the transient behavior of some peer-to-peer (P2P) networks. This work has two objectives: the first one is to study rigorously the transient behavior of some P2P networks whenever the information is replicated and disseminated according to epidemic-like dynamics, the second one is to use the insight gained from the previous analysis in order to predict how efficient are measures taken against P2P networks. A stochastic (Markov) model is introduced which extends a classical epidemic model and characterizes the P2P swarm

behavior in presence of free riding peers. Another model is also considered in which a peer initiates a contact with another peer chosen randomly. In both cases, the network is shown to exhibit a phase transition: a small change in the parameters causes a large change in the behavior of the network. It is shown, in particular, how the phase transition affects measures that content provider networks may take against P2P networks that distribute non-authorized music or books, and what is the efficiency of counter-measures.

6.3.1.2. Storage 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. Traditional redundancy schemes are replication and erasure codes. A new class of network coding (regenerating codes) has been proposed recently. In prior efforts, 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 tradional redundancy schemes. In [78], [14] they compare the performance of distributed storage systems that use regenerating codes to those that use traditional redundant codes.

6.3.1.3. Real-time control of contents download

The question of optimally prefetching data during the navigation over a hyperliked document has been studied by A. Jean-Marie, jointly with O. Morad (CNRS and University of Montpellier 2), as part of the VOODDO project (funded by the "Multimedia" Program of the ANR). A Markov-Decision theoretic model has been developped, and solution algorithms have been implemented. Preliminary results have been exposed in [71] and during the *Probability Models in Performance Analysis* workshop (London, September 2010).

6.3.1.4. BitTyrant

The success of BitTorrent has fostered the development of variants to its basic components. Some of the variants adopt greedy approaches aiming at exploiting the intrinsic altruism of the original version of BitTorrent in order to maximize the benefit of participating to a torrent. G. Neglia, together with D. Carra (Univ. Verona) and P. Michiardi (Institut Eurecom), has studied BitTyrant, a recently proposed strategic client. The research is described in Maestro 2008 activity report. Results have been extended and supported by PlanetLab experiments in [87].

6.3.2. Online social networks

In [40], K. Avrachenkov, in collaboration with B. Ribeiro and D. Towsley (Univ. Massachusetts), studies online social networks and proposes a hybrid sampling scheme that mixes independent uniform node sampling and random walk (RW)-based crawling. The authors show that their sampling method combines the strengths of both uniform and RW sampling while minimizing their drawbacks. In particular, the method increases the spectral gap of the random walk, and hence, accelerates convergence to the stationary distribution. The proposed method resembles PageRank but unlike PageRank preserves time-reversibility. Applying the hybrid RW to the problem of estimating degree distributions of social networks demonstrates promising results.

6.3.3. Document ranking and clustering on the Web

A random walk can be used as a centrality measure of a directed graph. However, if the graph is reducible, the random walk will be absorbed in some subset of nodes and will never visit the rest of the graph. In Google PageRank the problem was solved by the introduction of uniform random jumps with some probability. Up to the present, there is no final answer to the question about the choice of this probability. In [25], K. Avrachenkov and D. Nemirovsky, in collaboration with V. Borkar (Tata Institute of Fundamental Research, India), propose to use a parameter-free centrality measure which is based on the notion of a quasi-stationary distribution. Specifically, the authors suggest four quasi-stationary based centrality measures, analyze them and conclude that they produce approximately the same ranking.

In the third edition of WePS (Web Person Search) campaign K. Avrachenkov, in collaboration with E. Smirnova and B. Trousse (AXIS, INRIA) [66], has undertaken the person name disambiguation problem referred to as a clustering task. The aim was to make use of intrinsic link relationships among Web pages for name resolution in Web search results. To date, link structure has not been used for this purpose. However, Web graph can be a rich source of information about latent semantic similarity between pages. In their approach they hypothesize that pages referring to one person should be linked through the Web graph structure, namely through topically related pages. Their clustering algorithm has obtained the first official place in the WePS competition.

6.3.4. Fair resource allocation

"How can we allocate network resources fairly among different classes of users?" In [74], E. Altman, K. Avrachenkov and S. Ramanath introduce T-scale and multiscale fairness to address this question. This new concept allows them to distribute the network resources fairly among different classes of traffic. They demonstrate these concepts in a number of examples from spectrum allocation and indoor-outdoor scenarios.

6.4. Interdisciplinary study of the Internet access and of Network Neutrality

Participants: Eitan Altman, Manjesh Hanawal, Julio Rojas-Mora, Sulan Wong.

Since 2008, E. Altman has been developing and leading an interdisciplinary working group (with specialists in networking, economy and law) on the theme "Shaping Internet access: technological and socio-economic implications". [69]-[31] are among the fruits of this work. In these papers, S. Wong, E. Altman and J. Rojas-Mora examine the role of the Internet in the society as well as of the access to the Internet, not only from the technological point of view but also from the socio-economic side and as reflected by legislation and by court decisions.

Immediately after the announcement of the French public consultation on Net Neutrality in April 2010, this working group started (i) preparing a response to the consultation, and (ii) analyzing the major problems and issues that arise in network neutrality with the help of simplified mathematical models. The results of this work include

- a response to the French consultation in the form of answers to the questions raised by the government, which was co-signed by ten researchers[1]. In [70] they have analyzed this consultation comparing it to two other ones that took place in the same year in the USA and in Europe.
- studies involving game theory (both non-cooperative as well as cooperative game models are used, as well as combination of both). This work has resulted in publications in international conferences and journals [37], [36], [43].

There is one particular economic issue that is at the heart of the conflict over network neutrality which concerns the relationships between ISPs and content providers. The network is non-neutral whenever ISPs wish to favor one content provider over another one (have exclusive agreement, or whenever they wish to charge content providers for shipping content to the internauts – in addition to the price that ISPs already charge the internauts for their access).

In [37], E. Altman, J. Rojas-Mora and S. Wong, in cooperation with P. Bernhard (COMORE, INRIA), S. Caron (ENS Ulm) and G. Kesidis (Pennsylvania State Univ.), study the implications of being non-neutral and of charging the content providers (CP). Using non-cooperative game theoretic tools, they showed that if one provider, say the Internet service providers (ISP), has the power to impose payments on the other providers (the content provider), and to decide how much they should pay, the internauts suffer, but also the ISPs performance degrades. More precisely, they show that the only possible equilibrium would be characterized by prices that will induce zero demand from the internauts. This phenomenon does not occur if the price that one provider is requested to pay to the other is fixed by some regulator.

[1] see Eitan Altman, Chadi Barakat, Pierre Bernhard, Eric Fleury, Philippe Jacquet, Arnaud Legout, Corinne Touati, Bruno Tuffin, Sulan Wong. Our answer to the French Consultation over Network Neutrality, 9th April to 17th may, 2010. Available at http://www-sop.inria.fr/members/Eitan.Altman/DOC/conult-fr-sbm.pdf.

In [36], E. Altman and M. Hanawal in cooperation with R. Sundaresan (IISc, Bangalore) examine the effect of collusion, where an ISP and one or several CPs act as a cartel in setting prices. They derive the equilibrium prices and quantify the gains for the ISPs of having exclusive agreements with a CP.

In [43], E. Altman, S. Caron (ENS Ulm) and G. Kesidis (Pennsylvania State Univ.), explore the effects of content-specific (i.e. not *application* neutral) pricing, including multiple CPs providing different types of content. They also consider competition among multiple providers of the same type, including different models consumer stickiness (inertia or loyalty).

6.5. Game theory applied to networking

Participants: Eitan Altman, Konstantin Avrachenkov, Veeraruna Kavitha, Giovanni Neglia.

6.5.1. Power save mechanisms

Nowadays energy saving and reduction of electromagnetic pollution become important issues. One approach to these problems is the introduction of taxes on the energy dissipation. In [34], E. Altman and K. Avrachenkov, in collaboration with A. Garnaev (St.Petersburg State Univ.), investigate a taxation game between a user or a provider or a group of users and the taxation authority. This is a Stackelberg game where the taxation authority acts as a leader and users or service providers act as followers. They focus on the problem of finding taxation strategy in closed form and investigate how incomplete information of authorities about users impacts the equilibrium strategy.

6.5.2. Pricing mechanisms

Typically the cost of a product has many components. Various components correspond to the production chain steps through which the product goes before meeting a customer. This also takes place in the price formation in wireless networks. For instance, before transmitting customer data, a network operator has to buy some frequency range and also to establish contracts with electricity providers. In [50], E. Altman and K. Avrachenkov, in cooperation with Y. Hayel (LIA/Univ. of Avignon) and A. Garnaev (St. Petersburg State Univ.), establish the tarif formation scheme in wireless networks. Specifically, a hierarchical Stackelberg game with three levels, the user, the provider and the authority is analyzed.

6.5.3. Mobile association based on partial channel information

In [48], E. Altman, in collaboration with S-E. Elayoubi, M. Haddad and Z. Altman (all from Orange Labs), addresses the question of what decisions should be left to the user and what decision should be taken by the base station. In case the mobile takes the decision of association, it has to do so based on the channel information which is available but not in details: the base station only transmits information on whether the state is good, bad or in between. The problem is solved using a game theoretic formulation. These authors further study in [51] the question of how should the base station choose optimally which channel states should be declared as good, bad or in between, respectively.

6.5.4. Fair scheduling in presence of non-cooperation

In a cellular network, using an α-fair scheduler, the base station (BS) has to assign the slot to one of the mobiles based on truthful information from mobiles about their time-varying channel gains. A non-cooperative mobile may misrepresent its signal to the BS so as to maximize its throughput. In [55], V. Kavitha, E. Altman, R. Elazouzi (LIA/Univ. Avignon) and R. Sundaresan (IISc, Bangalore), have shown that the presence of non-cooperative users results in an α-fair bias in the channel assignment for small values of α while the existing schedulers are robust at high values of α. When the BS is aware of the non-cooperative mobiles and when the BS has additional knowledge of the statistics of the signals of the mobiles, new robust policies are proposed, which elicit the truthful signals from mobiles and achieve a Truth Revealing Equilibrium. The popular, iterative fair scheduling algorithms, proposed by H. J. Kushner and P. A. Whiting, are shown to fail under non-cooperation and are robustified against non-cooperation.

6.5.5. Jamming the signaling channel

In collaboration with S. Sarkar and P. Vaidyanathan (Univ. Pennsylvania), E. Altman investigates in [29] a game in which n channels are available to a mobile. The authors consider some adversarial node that can prevent the mobile from obtaining information on the state of k out of the n channels. This is the extended journal version that corresponds to a conference paper presented in the 2009 MAESTRO activity report.

The problem of jamming plays an important role in ensuring the quality and security of wireless communications, especially nowadays when wireless networks are quickly becoming ubiquitous. Jamming is a form of a denial of service attack in which an adversary can degrade the quality of the reception by creating interference. One can study jamming both in the purpose of protecting a wireless network against such attack or, on the contrary, in order to efficiently disrupt the communications of some adversary. In both cases, jamming is part of a conflict for which game theory is an appropriate tool. In [19], E. Altman and K. Avrachenkov, in cooperation with A. Garnaev (St. Petersburg State Univ.), consider jamming in wireless networks in the framework of zero-sum games with a-fairness utility functions. The base station has to distribute the power fairly among the users in the presence of a jammer. The jammer in turn tries to distribute its power among the channels to produce as much harm as possible. The Shannon capacity and the SNIR optimization are particular cases of the proposed more general a-fairness SNIR based utility functions.

6.5.6. Cognitive radio networks

Spectrum sharing in cognitive radio enables an efficient use of the scarce frequency spectrum by allowing the coexistence of licensed and unlicensed users in the same spectrum. In [72], K. Avrachenkov, in cooperation with X. Lei, L. Cottatellucci (Institut Eurecom), and A. Garnaev (St. Petersburg State Univ.), consider a slow fading multiuser environment with primary and secondary users. The secondary users have only partial knowledge of the channel and are subjected to transmitted power constraints by the primary users. Their communications are intrinsically affected by outage events. The authors propose and analyze two algorithms for joint rate and power allocation. In one algorithm, the secondary transmitters cooperate to maximize a common utility function accounting for the total throughput of the network. In a second approach based on a game framework, the secondary users aim at maximizing selfishly their own utilities. The latter approach shows better fairness properties at the expense of some global performance loss compared to the optimum cooperative approach.

6.5.7. Hierarchical routing games

Many structural results are known in routing games in which the link cost density (i.e. cost per unit of flow) is the same for all users and is given as a function of the total flow in that link. In [54], V. Kamble (Univ. Berkeley), E. Altman, R. El-Azouzi (LIA/Univ. Avignon) and V. Sharma (IISc, Bangalore), relax this structure and explore hierarchical routing games in which some flows (called primary flows) have strict priority over other flows (called secondary). The link cost density for primary flows is a function of the total amount of high priority flow in the link, whereas for secondary users. the density link cost depends on the total flow on the link from all classes. Uniqueness of the equilibrium is established under general conditions.

6.5.8. Control of epidemics with applications to propagation in computer networks

Back in 2008, E. Altman, in collaboration with T. Başar (Univ. Illinois) and F. De Pellegrini (Create-Net, Italy), started investigating and developing the theory of control of epidemic models having as goal to use these tools in computer networks. Their main achievements are listed below.

6.5.8.1. Epidemic with monotone structure

The first results obtained were in developing a theory adapted to epidemics with some monotone structure in the dynamics and in the cost. These results have now appeared in an extended journal version in [23]. On the other hand, they have extended these results in [45] from a scalar state space to a vector valued one. The authors identify optimal policies with a switching structure where one action is used until some time threshold and then another one is used thereafter. The context of these works as well as a number of generalizations which we are specified below, has been DTNs (Delay Tolerant Networks) and the object that is propagated

is assumed to be some content (such as music or data files). In [35], A. Azad joins the three coauthors and studies the problem in which not only do we control the power of mobiles but also their activation time.

6.5.8.2. Adversarial problems

In [39], E. Altman, T. Başar (Univ. Illinois) and V. Kavitha consider a multi-criteria control problem that arises in a delay tolerant network with two adversarial controllers: the source and the jammer. Open loop as well as closed loop optimal policies have similar structures. When the jammer has a tighter constraint on its energy resources than the source, both the policies have two switching times. Before the first switching time, the source and jammer policies are inner (are not pure) and are given by equalizer policies. After the first switching time, the jammer switches off and the source continues transmitting at maximum probability. After the second switching time, both the source and jammer are off. When the source has a tighter constraint on its energy resources than the jammer, there exists only one switching time before which the source and the jammer use inner equalizer policies and after which both are switched off. Dynamic programming techniques are used to obtain the above results.

A particular important adversarial situation arises in the propagation of e-viruses or of malware within a network. As these are often designed to damage the network as much as possible, the aim is to come up with methods for combatting those efficiently. E. Altman, in collaboration with S. Sarkar and M.H.R. Khouzani (Univ. Pennsylvania), has used the maximum principle in order to obtain the structure of optimal network policies against viruses [59], [58] [89].

Adversarial modeling is also used in robust control: when some parameters evolve in an unpredictable way, or when some noise that cannot be modelled well affects the dynamics or observations, one resorts to a worst case design, and attempts to obtain a strategy that can guarantee the best performance under any behavior of the noise or of the unknown parameter. In [39], E. Altman, in collaboration with A. Aram (Univ. Pennsylvania), T. Başar (Univ. Illinois), C. Touati (MESCAL, INRIA) and S. Sarkar (Univ. Pennsylvania), carries on this approach in a problem where both the dynamic and the cost are linear in the state and control. The author uses robust control techniques and manage to obtain an explicit solution for the optimal control as a function of the available information.

6.5.8.3. Applying risk sensitive control to delay tolerant networks

Our most important theoretical contribution to the theory of control of epidemics in computer network has been to identify tools from risk sensitive control which enable to obtain much more precise solutions as were available before. Indeed, consider a message that propagates within a set of mobile nodes, and assume that one is interested in maximizing probability that it would reach some destination (thanks to relaying) by some time T. This quantity can be expressed as the expectation of the exponential function of some integral cost. In the past, to minimize this cost, one maximized directy the integral. We have noticed that the original cost is the same as the risk sensitive cost which we often find in financial mathematics, and for which many algorithms are available. In [83], E. Altman and K. Kavitha, in collaboration with F. De Pellegrini (Create-Net, Italy) V. Kamble (Univ. Berkeley) and V. Borkar (TATA Institute, Mumbia), use risk sensitive theory in order to solve power control problems in DTNs.

6.5.8.4. Network design with socially-aware users

In many scenarios network design is not enforced by a central authority, but arises from the interactions of several self-interested agents. This is the case of the Internet itself. K. Avrachenkov and G. Neglia, together with J. Elias (Politecnico di Milano) and F. Martignon (Univ. Bergamo), have proposed two novel socially-aware network design games [49] [88]. In the first game they have incorporated a socially-aware component in the users' utility functions, while in the second game they have adopted a Stackelberg approach, where a leader (e.g., the network administrator) architects the desired network buying an appropriate subset of network's links, driving in this way the users to overall efficient Nash equilibria. In [75] the same researchers, together with Leon Petrosyan (St Petersburg State Univ.), have studied the advantages to use Nash Bargaining Solution, rather than Shapley Value, to solve Cooperative Network Formation games.

6.5.9. WiFi networks

In WiFi networks, mobile nodes compete for accessing the shared channel by means of a random access protocol called Distributed Coordination Function (DCF), which is long term fair. Selfish nodes could benefit from violating the protocol and increasing their transmission probability. G. Neglia, together with I. Tinnirello and L. Giarré (Univ. Palermo) have been studying the interaction of selfish nodes in the last two years (the research activity is described in Maestro 2009 activity report). In [68], they have proposed some new mechanisms for channel access, that incite s elfish nodes to operate at Pareto optimal equilibria. The issue of how to implement these mechanisms has been addressed as well.

6.6. Stochastic processes, queueing, control theory and game theory

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

6.6.1. Convergence of rolling horizon control

In collaboration with E. Della Vecchia and S. Di Marco (National University of Rosario, Argentina), A. Jean-Marie has investigated the performance of the Rolling Horizon heuristic for optimal stochastic control when the optimization criterion is the long-term average expected gain [46]. They have shown that convergence occurs under quite general assumptions, weaker than the usual "unichain" assumption. As a side result, they have shown that a stopping rule for the Value Iteration algorithm, conjectured by Puterman, is not correct in general.

6.6.2. Advances in queueing theory

In [27], K. Avrachenkov in collaboration with U. Yechiali (Tel Aviv Univ.), considers systems of tandem blocking queues having a common retrial queue. The model can represent dynamics of short TCP transfers in the Internet. Analytical results are available only for a specific example with two queues in tandem. They propose approximation procedures involving simple analytic expressions, based on mean value analysis (MVA) and on fixed point approach (FPA). The mean sojourn time of a job in the system and the mean number of visits to the orbit queue are estimated by the MVA which needs as an input the fractions of blocked jobs in the primary queues. The fractions of blocked jobs are estimated by FPA.

6.6.3. Analysis of DPS in overload and applications to TCP

In [21], E. Altman, T. Jimenez (LIA/Univ. Avignon) and D. Kofman (Télécom ParisTech) study the rate of growth of the delays as well as the rate of growth of the population size of sessions in a network at overload, which they model as a DPS (Discriminatory Processor Sharing). They obtain a fixed point equation that allows them to compute the growth rate for any stationary ergodic service and arrival time process. They then study how suitable are the results for describing the session level performance of file transfers in the Internet.

6.6.4. Markov decision evolutionary games

Evolutionary games concern the evolution of populations that interact with each other through many simultaneous pairwise interactions. The result of each such local interaction is determined by the actions of the individuals involved. In [20], E. Altman and Y. Hayel (LIA/Univ. Avignon) extend the theory of evolutionary games to include also a notion of a state of each individual; the results (and payoff) of the interactions are now determined not only by the actions taken by individuals but also by their individual states. The actions and the current individual states further determine the transition probabilities of these states. The theory is applied to power control in wireless networks. This application as well as applications to contributions to the theory evolutionary games are surveyed in [30] by H. Tembine (Supelec), E. Altman, R. El-Azouzi and Y. Hayel (LIA/Univ. Avignon).

6.6.5. Singular perturbation theory

In [26], K. Avrachenkov, in collaboration with V. Ejov and J. Filar (Univ. South Australia), studies multivariate perturbations of algebraic equations. In general, it is not possible to represent the perturbed solution as a Puiseux-type power series in a connected neighborhood. For the case of two perturbation parameters, the authors provide a sufficient condition that guarantees such a representation. Then, the authors extend this result to the case of more than two perturbation parameters. The study is motivated by the perturbation analysis of a weighted random walk on the Web Graph. As an instance of the latter, the stationary distribution of the weighted random walk, the so-called Weighted PageRank, may depend on two (or more) perturbations.

6.6.6. Game theory, altruism and the degree of cooperation

In [41], A. Azad and E. Altman, in cooperation with R. El-Azouzi (LIA/Univ. Avignon), introduce a parametrized level of cooperation. The utility of a player is assumed to be a weighted average of performance measures of other players. Varying the weight gives all the cooperation spectrum from non-cooperation till altruism. The authors apply the concept to routing games and investigate the properties of the equilibria as a function of the degree of cooperation.

7. Contracts and Grants with Industry

7.1. ADR "Semantic Networking" and "Self Optimization in Wireless Networks" of INRIA Alcatel-Lucent Bell Labs joint laboratory (2008–2011)

MAESTRO participates in the ADR (Action de Recherche/Research Action) "Semantic Networking" (SEMNET) and "Self Optimization in Wireless Networks" (SELFNET), two of the three ADRs of the INRIA ALCATEL-LUCENT BELL LABS joint laboratory. These ADRs started on January 1st 2008 and will last for four years.

Isabelle Guérin Lassous (INRIA project-team RESO) is the coordinator for INRIA of the ADR SEMNET and Bruno Gaujal (head of INRIA project-team MESCAL) is the coordinator for INRIA of the ADR SELFNET. ALTCATEL-LUCENT coordinators of ADRs SEMNET and SELFNET are Ludovic Noirie and Laurent Thomas, respectively.

http://inria.bell-labs.commonlab.homeip.net/.

7.1.1. ADR "Semantic Networking"

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Alberto Blanc, Philippe Nain.

The new paradigm of "semantic networking" for the networks of the future brings together "flow-based networking", "traffic-awareness" and "self-management" concepts to get "plug-and-play" networks. The natural traffic granularity is the flow. MAESTRO's task is to elaborate on the scheduling of flows in routers having in mind the fairness among flows with different round-trip times. A joint INRIA ACATEL-LUCENT patent has been filed in 2009 (inventors for INRIA: S. Alouf, K. Avrachenkov, D. Carra, P. Nain).

E. Altman participates with P. Vicat-Blanc Primet (INRIA project-team RESO) in the supervision of the PhD thesis of Dinil Mon Divakaran (INRIA project-team RESO), which aims at evaluating the advantages of introducing very large packets that would coexist with other packets whose size will not change.

7.1.2. ADR "Self Optimizing Wireless Networks"

Participants: Eitan Altman, Sreenath Ramanath.

E. Altman is responsible for INRIA of the work package on the "Design of Pico Cell Networks" whose objective is to increase the capacity with lower energy requirements.

7.2. Grant from Orange Labs on "Content-Centric Networking" (October 2010 - September 2012)

Participants: Sara Alouf, Konstantin Avrachenkov, Philippe Nain, Giovanni Neglia.

The objective of this grant (CRE) is to develop mathematical models for the analysis of Content-Centric Networks (CCN). This research focuses on routing and caching policies.

P. Nain is responsible for INRIA. This work is done in collaboration with C. Barakat (PLANETE, INRIA).

8. Other Grants and Activities

8.1. International initiatives

8.1.1. INRIA Associate Team DAWN - Distributed Algorithms for Wireless Networks (2008-2011)

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Amar Azad.

MAESTRO has privileged collaborations with the Indian Institute of Science (IISC) at Bangalore, the Tata Institute of Fundamental Research at Mumbai, and the University of Pennsylvania, through the INRIA Associate Team "DAWN" (an INRIA program). DAWN stands for "Distributed Algorithms for Wireless Networks". It was launched on January 1st, 2008.

DAWN involves three INRIA project-teams teams (MAESTRO, the coordinator, MESCAL and TREC) and three foreign teams. The main foreign team is the IISC (Bangalore, India) with Prof. A. Kumar (coordinator), R. Sundaresan, V. Sharma and A Chokalingam. Two other foreign teams are TIFR Mumbay with V. Borkar (Tata Institute, Mumbai)f Pennsylvania with S. Sarkar.

DAWN focuses on "Emerging Strategies for Wireless Communication Networks". More specifically, the project objectives are to model, analyze, optimize and invent protocols for both cellular as well as ad hoc wireless network.

DAWN was created in the perspective of creating a joint laboratory between INRIA and IISC at Bangalore (see "Inedit" magazine No. 63. Bangalore: Managing connections on wireless networks).

http://www-sop.inria.fr/maestro/Equipe-Associee.html.

8.2. European initiatives

8.2.1. ICT STREP ECODE (2008-2011)

Participants: Sara Alouf, Konstantin Avrachenkov, Giovanni Neglia.

MAESTRO is a partner of the ICT European STREP Project ECODE on "Experimental COgnitive Distributed Engine". K. Avrachenkov is the coordinator for MAESTRO.

ECODE is a 3-year STREP project (running from Sept. 2008 to August 2011) co-funded by the European Commission under the Framework Programme 7 (FP7), addressing the Strategic Objective ICT-2007-1.6 "New paradigms and experimental facilities". There are seven partners involved and MAESTRO, together with INRIA project-team PLANETE, is one of them.

The goal of the ECODE project is to develop, implement, and validate experimentally a cognitive routing system that can meet the challenges experienced by the Internet in terms of manageability and security, availability and accountability, as well as routing system scalability and quality. By combining both networking and machine learning research fields, the resulting cognitive routing system fundamentally revisits the capabilities of the Internet networking layer so as to address these challenges altogether. MAESTRO's task is to design and evaluate flow management schemes that can deal with potentially sampled traffic information.

http://www.ecode-project.eu/.

8.3. National initiatives

8.3.1. ANR Verso ECOSCELLS (11/2009–10/2012)

Participants: Eitan Altman, Konstantin Avrachenkov, Philippe Nain.

ANR VERSO ECOSCELLS (Efficient Cooperating Small Cells) aims at developing algorithms and solutions which will be required for the deployment of small cell networks. The theoretical studies will define and solve the models needed to understand the behavior of radio channels, and will design the algorithms which will allow the exploitation of the diversity (user, spatial, interference, etc.) in these networks. The consortium gathers two main industrial groups in the telecommunication domain (ALCATEL-LUCENT BELL LABS (leader) and ORANGE LABS), together with three leading SMEs (3ROAM, SEQUANS and SIRADEL) and six academic partners (UNIVERSITY OF AVIGNON, INRIA through its project-teams MAESTRO, MASCOTTE and SWING, INSTITUT EURECOM, LAAS-CNRS and LABORATOIRE DES SIGNAUX ET SYSTÈMES/SUPELEC).

http://perso.citi.insa-lyon.fr/hrivano/contrats/ecoscells.php

8.3.2. ANR Télécommunications WINEM (2007–2010)

Participants: Sara Alouf, Eitan Altman, Amar Azad, Vincenzo Mancuso.

This project, called WINEM, for "WiMAX Network Engineering and Multihoming," started on December 1st, 2006. Initially planned for three years, the project has been granted an extension until May 31st, 2010. After the withdrawal of Motorola from the project and the increased interest for LTE (Long-Term Evolution), the objectives of the project have been updated. The focus will be on: evaluating the coverage and capacity when relaying is possible, optimal joint radio resource management, evaluating energy saving mechanisms, and integrating the WiMAX simulators SimulX and Odysse. The project's current partners are: FRANCE TELECOM R&D, INSTITUT TELECOM (ENST Bretagne and INT), INRIA (INRIA project-teams DYONISOS and MAESTRO), INSTITUT EURECOM, and LIA (University of Avignon).

S. Alouf was the coordinator for INRIA.

http://www.lia.univ-avignon.fr/index.php?id=502.

8.3.3. ANR Multimedia VOODDO (2008–2010)

Participant: Alain Jean-Marie.

Members of MAESTRO participate in this research project, coordinated by the VODDNET company, and involving researchers of the LIRMM (University of Montpellier II and CNRS). The global objective of this project is the development of an innovative visualization interface for video contents, based on a safe, reliable and optimized storage and transport infrastructure. The research bears presently on the determination of efficient real-time contents download algorithms.

8.3.4. INRIA Cooperative Research Initiative (ARC) POPEYE (2008-2010)

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

The ARC POPEYE focuses on the behavior of large complex systems that involve interactions among one or more populations. "Population" refers to a large set of individuals, that may be modeled as individual agents, but that will be often modeled as a continuum of non-atomic agents. The project brings together researchers from different disciplines: computer science and network engineering, applied mathematics, economics and biology. This interdisciplinary collaborative research aims at developing new theoretical tools as well as at their applications to dynamic and spatial aspects of populations that arise in various disciplines, with a particular focus on biology and networking.

There are three INRIA project-teams participating in this project (MAESTRO, MESCAL and TOSCA), three INRA groups (Biostatistics and Spatial Processes group in Avignon, Ecology of Insect Pararasitoids group in Sophia-Antipolis, LAMETA group in Montpellier) and three groups from universities (Combinatorics and Optimization group from the University of Pierre and Marie Curie in Paris, LIA from University of Avignon, and I3S from University of Nice Sophia Antipolis).

E. Altman and A. Jean-Marie coordinate the ARC POPEYE.

http://www-sop.inria.fr/maestro/POPEYE/home.html.

8.4. Invited scientists

Europe:

Samuli Aalto (Aalto University, Finland, May 28 - June 2, 2010),
Andrey Garnaev (St. Petersburg State University, Russia, September 15 - October 15, 2010 and November 2 - December 17, 2010),
Ruslana Goricheva (Russian Academy of Sciences, Russia, October 11-15, 2010),
Peter Jacko (Basque Center for Applied Mathematics, Spain, April 6 - May 31, 2010),
Evsey Morozov (Petrozavodsk State University, Russia, October 11-15, 2010),
Emilio Leonardi (Politecnico di Turino, Italy, March 29, 2010),
Maaike Verloop (Basque Center for Applied Mathematics, Spain, May 17-21, 2010).

America:

Tamer Başar (University of Illinois at Urbana-Champaign, IL, USA),
Don Towsley (University of Massachusetts at Amherst, MA, USA, January 25-29, 2010).

Asia:

Rajesh Sundaresan (Indian Institute of Science (IISc), Bangalore, India, May 24 - June 4, 2010).

Oceania:

Jerzy Filar (University of South Australia, Australia, June 9-28, 2010),
Ali Jahromi (University of South Australia, Australia, July 12-31, 2010).

8.5. Visits of Maestro staff to other research institutions

E. Altman visited the Indian Institute of Science (IISc) in Bangalore from January 1 to January 14, 2010.

K. Avrachenkov visited the Newton Institute in Cambridge, UK from May 23 to June 10, 2010, and Urtzi Ayesta at Basque Centre for Applied Mathematics, Spain from October 8 to October 22, 2010.

A. Jean-Marie visited the GERAD (Montréal, Canada), from April 26 from May 20, 2010, and the Universidad Nacional de Rosario (Rosario, Argentina), from November 22 to December 2, 2010.

H. Manjesh visited the Indian Institute of Science (IISc) in Bangalore from August 1 to October 20, 2010.

P. Nain visited Politecnico di Torino on April 16, 2010.

G. Neglia visited Boston University, MA, USA (1 day in December) and gave a talk.

S. Ramanath visited Indian Institute of Science (IISc) and Bell Labs in Bangalore from December 14, 2009 to January 16, 2010.

A. Silva visited Alcatel-Lucent in Murray Hill, NJ, USA, from March 1 to May 31, 2010.

Y. Xu visited Prof. Di Wu at the School of Information Science, Sun Yet-Sen University, Canton, China from December 7 to December 9, 2010.

9. Dissemination

9.1. Leadership within scientific community

9.1.1. Editorial activities

E. Altman is an Associate Editor of *Journal of Economics, Dynamics and Control* (JEDC), *ACM/Kluwer Wireless Networks* (WINET), *Journal of Discrete Event Dynamic Systems* (JDEDS), and *Computer Communications* (COMCOM) Elsevier. He was Co-editor of two Special Issues of Computer Networks: (1) "New Network Paradigms", Vol. 54 Issue 6, 29 April 2010, and "Future Wireless Internet", available online in Science Direct since October 2010.

K. Avrachenkov is an Editor of *Performance Evaluation*.

A. Jean-Marie is an Associate Editor for *RAIRO Operations Research*.

P. Nain is the Editor-in-Chief of *Performance Evaluation* and an Associate Editor of *Operations Research Letters*.

9.1.2. Participation in technical program committees

E. Altman was a program committee member of the following conferences: 5th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (Bionetics 2010; December 1-3, 2010, Boston, MA, USA), Conference on Decision and Game Theory for Security (GameSec 2010; November 22-23, 2010, Berlin, Germany).

K. Avrachenkov was a program committee member of the following conferences: 10th International Conference on Next Generation Wired/Wireless Networking (NEW2AN 2010; August 23-25, 2010, St. Petersburg, Russia), 3rd International Workshop on Multiple Access Communications (MACOM 2010; September 13-14, 2010, Barcelona, Spain), 2nd International Conference on Advances in Future Internet (AFIN 2010; July 18-25m 2010, Venice, Italy), Euro-NF International Conference on Network Control and Optimization (NetCoop 2010; November 29 - December 1, 2010, Ghent, Belgium).

A. Jean-Marie was a program committee member of the following conferences: ACM Sigmetrics 2010 (June 14-18, 2010, New York, NY, USA), 12th Workshop on Mathematical performance Modeling and Analysis (MAMA 2010; June 18, 2010, New York, NY, USA), 7th International Conference on Quantitative Evaluation of SysTems (QEST 2010; September 15-18, 2010, Williamsburg, VA, USA), 25th International Symposium on Computer and Information Sciences (ISCIS 2010; September 22-24, 2010 - London, UK).

P. Nain was a program committee member of the following conference: 25th International Symposium on Computer and Information Sciences (ISCIS 2010; September 22-24, 2010 - London, UK), 12th Workshop on Mathematical performance Modeling and Analysis (MAMA 2010; June 18, 2010, New York, NY, USA), IFIP Performance 2010 (November 16-19, Namur, Belgium).

G. Neglia was a program committee member of the following conferences: IEEE Infocom 2011 (April 10-15, 2011, Shangai, China), IEEE International Conference on Communications (ICC 2011; June 5-9, 2011, Kyoto, Japan), ACM Mobihoc 2010 (September 20-24, 2010, Chicago, IL, USA) and IEEE International Symposium on Wireless Pervasive Computing (ISWPC 2010; May 5-7, 2010, Modena, Italy). He chaired with Srinivas Shakkottai (Dept. of ECE at Texas A&M University) the track on Network Algorithms, Performance Evaluation and Theory (NAPET) of 19th International Conference on Computer Communications and Networks (ICCCN 2010; August 2-5, 2010, ETH Zurich, Switzerland) and was in the organizing committee of the 6th Spain, Italy and Netherlands Meeting on Game Theory (SING 6; July 7-9, 2010, Palermo, Italy).

9.1.3. Conferences, meetings and tutorial organization

E. Altman has been the chairman of the steering committee of the 9th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt'10; May 31 - June 4, 2010, Avignon, France) and of the Euro-NF International Conference on Network Control and Optimization (NetCoop 2010; November 29 - December 1, 2010, Ghent, Belgium). He has been the co-general chair of the workshop IOFC Istanbul, 2010 and the TPC chair of WiOpt 2010.

9.1.4. Participation in thesis committees

S. Alouf participated in the PhD thesis committee of

- Abdulhalim Dandoush (March 29, 2010, University of Nice Sophia Antipolis) as the thesis co-advisor.

E. Altman participated in the Habilitation thesis committee (HDR) of

- Samson Lasaulce (October 7, 2010, Supelec),

and in the PhD thesis committee of

- Thomas Olwal (November 2, 2010, F'SATIE/TUT, Pretoria, South Africa and University Paris 12/LISSI Lab.) as a reviewer,
- Amar Azad (November 26, 2010, University of Avignon and the Vaucluse) as the thesis co-advisor,
- Alonso Silva (June 7, 2010, Supelec) as the thesis co-advisor.

K. Avrachenkov participated in the PhD thesis committees of

- Pablo Soldati (February 2, 2010, KTH, Sweden), Danil Nemirovsky (2 July 2010, University of Nice Sophia Antipolis) as a reviewer,
- Andrey Lukyanenko (November 17, 2010, University of Helsinki, Finland) as a reviewer.

A. Jean-Marie participated in the Habilitation thesis committee of

- Thomas Bonald (January 15, 2010, University of Paris 6) as a reviewer,

and in the PhD thesis committee of

- Abdulhalim Dandoush (March 29, 2010, University of Nice Sophia Antipolis) as president,
- Zafar Shahid (September22, 2010, University of Montpellier 2) as president,
- Nicolas Gast (September 29, 2010, University of Grenoble) as a reviewer,
- Julian Geraldes Monteiro (November 16, 2010, University of Nice Sophia Antipolis) as president,
- Julien Champ (December 13, 2010, University of Montpellier 2).

P. Nain participated in the Habilitation thesis committee of

- David Coudert (March 2010, University of Nice Sophia Antipolis),
- Fabio Martignon (December 10, 2010, University Pierre and Marie Curie, Paris) as a reviewer,

and in the PhD thesis committee of

- Daniele Croce (April 16, 2010, Politecnico di Torino) as a reviewer,
- Abdulhalim Dandoush (March 29, 2010, University of Nice Sophia Antipolis) as the thesis co-advisor.

9.1.5. HDR and PhD theses

The following HDR (Habilitation à diriger des recherches) was defended in 2010:

Konstantin Avrachenkov HDR Thesis from the University of Nice Sophia Antipolis: "Stochatic Methods for TCP/IP Networks and the WWW" [12]. Graduation on April 29, 2010.

The following PhD theses were defended in 2010:

Amar Azad PhD Thesis from the University of Avignon and the Vaucluse: "Advances in Network Control and Optimization" [13]. Graduation on November 26, 2010. Advisors: S. Alouf and E. Altman.

Abdulhalim Dandoush PhD Thesis from the University of Nice Sophia Antipolis: "Analysis and Optimization of Peer to Peer Storage Systems" [14]. Graduation on March 29, 2010. Advisors: S. Alouf and P. Nain

Danil Nemirovsky PhD Thesis from the University of Nice Sophia Antipolis (thesis in " co-tutelle" with St Petersbourg State University): "Monte Carlo Methods and Markov Chain Based Approaches for PageRank Computation" [15]. Graduation on July 2, 2010. Advisor: K. Avrachenkov.

Alonso Silva PhD Thesis Supelec (Gif-sur-Yvette, France): "Design and Optimization of Wireless Networks for Large Populations" [16]. Graduation on June 7, 2010. Advisors: E. Altman and M. Debbah (Supelec).

9.1.6. Research administration

S. Alouf is a member of the Doctoral Committee of INRIA Sophia Antipolis.

A. Jean-Marie

- is the scientific coordinator of INRIA activities in Montpellier.
- is member of the managing sub-committee of the Project-Team Committee of the INRIA Sophia Antipolis - Méditerranée research center.
- is co-head of the APR (Algorithms and Performance of Networks) project-team of the LIRMM Laboratory, a joint research unit of CNRS and the University of Montpellier II.
- was a member of the Recruiting Committee in Computer Science at the École Normale Supérieure, Paris.
- is a member of the Steering Committee of the GDR RO, a national research initiative on Operations Research sponsored by the CNRS.

P. Nain

- has been the Scientific Deputy of the Research Center of INRIA Sophia Antipolis - Mditerrane and the Chair of its Project-team Committee from July 2007 to June 2010.
- is Head of project-team MAESTRO.
- has been a member of the management of the Research Center of INRIA Sophia Antipolis - Méditerranée from July 2005 to June 2010.
- has been a member of the Evaluation Committee of INRIA until June 2010.
- was a member of the Recruiting Committee of INRIA junior research scientists (CR2 and CR1) at INRIA Sophia Antipolis - Méditerranée and a member of the Recruiting Committee of INRIA senior research scientists (DR2).

9.1.7. Miscellaneous (nominations, awards, etc.)

- A. Dandoush and A. Jean-Marie received the Best Paper Award of the 3rd International Conference on Communication Theory, Reliability, and Quality of Service (CTRQ2010; June 13, 2010, Athens, Greece) [28].
- E. Altman, A. Jean-Marie and P. Nain are (elected) members of IFIP WG7.3 on "Computer System Modeling".
- P. Nain is the Vice-Chair of the IFIP WG7.3 working group on "Computer System Modeling" and a Member of the Board of Directors of SIGMETRICS (elected for the period June 30, 2007 – July 1, 2011).

9.2. Teaching

E. Altman taught a 32hrs course on "Game Theory with Network Applications" in Politecnico di Milano and 9hrs on the same topic at ENS Lyon.

K. Avrachenkov was in charge of the course on “Linear Algebra and Nemerical Methods” in the Engineering Program EuroAquare at PolyTech Nice - Sophia Antipolis (15hrs).

S. Alouf was in charge of the course on “Probability and Statistics” in the Engineering Program in the Polytech’Nice Sophia Antipolis School (8hrs of lecture, 22hrs of assignments).

A. Dandoush participated as a temporary research and teaching assistant (ATER) in the courses on “Introduction to Object Oriented Programming”, “Information systems (Linux)” and “Advanced Object Oriented Programming (in Java)” in the Bachelor Program on “Computer Science/ MIAGE” of the University of Nice Sophia Antipolis (66hrs).

A. Jean-Marie taught a Master in Computer Science course on “Metrology and Quality of Service for Networks” (12hrs), a Graduate Class on “Advanced Markov Modeling” (18hrs), both at the University of Montpellier II, and a Master course on “Fundamentals of Network Modeling” (12hrs) at the University of Paris 6.

D. Mazauric taught courses on “Algorithms and Complexity” (32hrs) and on “Functional Programming (Scheme)” (32hrs) both in the Bachelor in Computer Science Program of the University of Nice Sophia Antipolis

P. Nain taught a course on “Performance Evaluation of Networks” (Master IFI, specialty Ubinet, PolytechNice-Sophia, 21hrs).

G. Neglia taught courses in “Probability and Statistics” (PolytechNice-Sophia, 1hr of lectures, 20hrs of assignments) and in “Performance Evaluation of Networks” (Master IFI, specialty Ubinet, PolytechNice-Sophia, 15hrs of lectures in the academic year 2009-2010 and 6hrs in the academic year 2010-2011). He has been responsible for the final projects of the Master Ubinet in the academic years 2009-2010 and 2010-2011. He gave a lesson on “Introduction à l’ordinateur" at the Ecole Gasnier Guy Sainte Bathilde, Chelles (November 12, 2010, 1.5 hrs), and presented the activities of MAESTRO to students from ENS Cachan (December 10, 2010).

D. Nemirovsky taught a course on “Mathematical Modeling in Networks” at St. Petersburg State University (15hrs of lecture, 2hrs of homework).

9.3. Participation in scientific events

9.3.1. Conferences and workshops

E. Altman gave presentations at the 3rd International Conference on Communication Systems and NetworkS (COMSNETS; Jan 5-8, Bangalore, India), Infocom (March 15-19, San Diego, CA, USA) and at the 9th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt’10; May 31 - June 4, 2010, Avignon, France).

K. Avrachenkov gave presentations at the 16th Conference of the International Linear Algebra Society (ILAS; June 21-25, 2010, Pisa, Italy), the Workshop on Modern Trends in Controlled Stochastic Processes (12-16 July 2010, Liverpool, UK) and the Modern Stochastics Conference (Kiev, Ukraine, 7-11 September 2010).

A. Jean-Marie gave a presentation at the 3rd International Conference on Communication Theory, Reliability, and Quality of Service (CTRQ 2010, June 13-19, 2010, Athens/Glyfada, Greece), the 25th International Symposium on Computer and Information Sciences (ISCIS 2010, September 22-24, 2010, London, UK), and attended the 11th congress of the French Society for Operations Research and Decision Aid (Roadef 2010, February 24-26, 2010, Toulouse, France).

V. Kavitha gave presentations at the following conferences: 3rd International Conference on Communication Systems and NetworkS (COMSNETS; Jan 5-8, Bangalore, India), MobiOpp (2010, Feb 22-23, Pisa, Italy), Infocom (March 15-19, San Diego, CA, USA) and 9th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt'10; May 31 - June 4, 2010, Avignon, France).

D. Mazauric presented a poster at ACM Sigmetrics 2010 (June 14-18, 2010,New York, NY, USA) and gave a presentation at the 12th "Journes Graphes et Algorithmes" (JGS'10; November 8-10, 2010, Marseille, France).

G. Neglia gave a presentation on "Routing in Quasi-Deterministic Intermittently Connected Networks" at the Italian Networking Research workshop (January 13–15 2010, Bormio, Italy).

S. Ramanath gave presentations at 3rd International Conference on Communication Systems and NetworkS (COMSNETS; Jan 5-8, Bangalore, India), IEEE Infocom (March 15-19, San Diego, CA, USA), 9th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt'10; May 31 - June 4, 2010, Avignon, France), 2nd IEEE International Workshop on Indoor and Outdoor Femto Cells (IOFC 2010; Sep 26, Istanbul, Turkey) and presented a poster at IFIP Performance 2010 (November 16-19, Namur, Belgium).

Y. Xu presented a poster at IFIP Performance 2010 (November 16-19, Namur, Belgium).

9.3.2. Invited talks

E. Altman gave an invited talk at Comsnets (Jan 5-8, 2010, Bangalore, India) entitled "Restricting Internet Access: Ideology and Technology".

K. Avrachenkov gave an invited talk entitled "Improving Random Walk Estimation Accuracy with Uniform Restarts" at Basque Centre for Applied Mathematics on October 28, 2010, and an invited talk entitled "Retrial queues and networks with constant retrial rate" at the Euro-NF International Conference on Network Control and Optimization (NetCoop 2010; November 29 - December 1, 2010, Ghent, Belgium).

A. Jean-Marie gave an invited talk entitled "Downloading Optimally in Real-Time" at the workshop "Probability Models in Performance Analysis" held at The Royal Society London on September 21, 2010 in honor of Erol Gelenbe's 65th birthday.

P. Nain gave an invited talk entitled "Contend Dissemination in Peer-to-Peer Networks" at the workshop "Probability Models in Performance Analysis" held at The Royal Society London on September 21, 2010 in honor of Erol Gelenbe's 65th birthday.

G. Neglia gave a presentation on "Distributed Sub-gradient Method for Delay Tolerant Networks" at Boston University (October 29 2010, Boston, MA, USA).

J. Rojas-Mora gave an invited talk at the Euro-NF International Conference on Network Control and Optimization (NetCoop 2010; November 29 - December 1, 2010, Ghent, Belgium) entitled "Public Consultations on Net Neutrality 2010".

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