INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team MAESTRO

Models for Performance Analysis and Control of Networks

Sophia Antipolis - Méditerranée

THEME COM

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2. Overall Objectives

2.1. Presentation of MAESTRO

MAESTRO is an INRIA project-team whose members are mainly located in Sophia Antipolis; E. Altman is located at Laboratoire Informatique d'Avignon (LIA) in Avignon, and A.-E. Baert and A. Jean-Marie are both located at LIRMM in Montpellier. 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.

Research activities in 2008 have focused on the following issues:

- performance evaluation of wireless, mobile, ad hoc and sensor networks, with the support of the IST IP BIONETS, Network of Excellence EURO-FGI/NF, INRIA Associate Team DAWN and the ARC POPEYE;
- pico-cell based wireless networks, with the support of the ADR "Self Optimization in Wireless Networks" (SELFNET) grant of INRIA ACATEL-LUCENT joint laboratory;
- flow-based networking, with the support of the ADR "Semantic Networking" (SEMNET) grant of INRIA ACATEL-LUCENT joint laboratory;
- analysis of the WiMAX protocol, with the support of the ANR grant WINEM;
- data replication and distribution problems in a distributed video-on-demand systems, with the support of the ANR grant VOODDO;
- analysis of sized-based scheduling schemes, and performance evaluation of peer-to-peer protocols using stochastic models, with the support of Network of Excellence EURO-FGI/NF;
- game theory methods for wireless networks, with the support of the IST IP BIONETS, Network of Excellence EURO-FGI/NF, Egide ECO-NET and ARC POPEYE;
- development of new perturbation methods, with the support of the Australian Research Council Discovery grant.

2.2. Highlights of the year

Awards: A. Silva, received the Best Student Paper Award of the VALUETOOLS 2008 conference (Oct. 20–24, 2008, Athens, Greece) for his paper entitled "The Space Frontier: Physical Limits of Multiple Antenna Information Transfer", coauthored with R. Couillet, S. Wagner and M. Debbah.

Keynotes: E. Altman was a keynote speaker at the *First IEEE International Workshop on Cognitive Radio and Networks* (CRNETS 2008, Sept. 15, 2008, Cannes, France) held in conjunction with the *19th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications* (PIMRC 2008).

Organizations: MAESTRO was very active in the organization of the 3rd VALUETOOLS conference (Oct. 20–24, 2008, Athens, Greece). Responsabilities include: steering committee co-chair (E. Altman), webmaster and local organizer (E. Deriche), workshops co-chair (S. Alouf), co-chair of SMCTools workshop (K. Avrachenkov), and co-chair of Inter-Perf workshop (G. Neglia).

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;
- theory of dynamical discrete-event systems: queues, fluid approximation, network calculus;
- 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, delay tolerant networks (DTN), power control, medium access control, transmission rate control, redundancy in source coding, mobility models, coverage, routing.

5. Software

5.1. Web Graph Analyzer

Participants: Konstantin Avrachenkov [correspondant], Danil Nemirovsky, Elena Smirnova.

K. Avrachenkov, D. Nemirovsky and E. Smirnova 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 2008, the development of the visualization module has been pursued and a clustering module has been added to the software.

5.2. Autonomous Engine for Image Search

Participants: Konstantin Avrachenkov [correspondant], Oleg Smirnov, Philippe Nain.

In collaboration with CANON (within ANR RIAM Spi3-Pro – see 2007 MAESTRO activity report), a Web crawler for crawling images from targeted Web Sites have been developed. This crawler is used by Canon in a software which helps independent photographers to detect uncopyright use of their material. Distinctive features of this crawler include efficient sub-optimal refresh policy, extracting images from Flash based Web sites and managing several HTTP connections inside one Java thread. The efforts allocated in 2008 have focused on optimizing the performance of the crawler for the Autonomous Engine for Image Search. (ANR RIAM Spi3-Pro officially ended at the end of 2007 but an extension was granted to spend in 2008 the leftover of the allocated budget.)

6. New Results

6.1. Congestion control and IP traffic characterization

Keywords: *AIMD*, *AQM router*, *TCP*, *TCP Westwood+*, *long/short-lived flows*, *the role of information in flow control*, *uniform sampling*.

Participants: Eitan Altman, Konstantin Avrachenkov, Alberto Blanc, Giovanni Neglia, Natalia Osipova.

6.1.1. How much feedback does TCP need?

Participant: Eitan Altman.

In collaboration with T. Başar (University of Illinois at Urbana-Champaign, USA) and N. Malouch (University Paris 5), E. Altman studies in [14] tradeoffs that influence the amount of feedback information that the source should get from the network. Their considerations in this research include the following points: (i) the signaling information – such as acknowledgments in the TCP protocol – may be sharing common resources with the data transmissions, and thus feedback comes at the cost of less bandwidth for the data traffic, (ii) the amount of signaling may have an impact on stability: if one wishes to allow the amount of feedback to depend on the state (the window size of TCP) then one should carefully choose this dependence in order to avoid instabilities due to the delays.

The authors propose various dynamic ways to control the amount of feedback as a function of the window size. Their research relies on the existing mechanism in TCP to reduce the ACK signaling by implementing the delayed ACK option, where every N received packets trigger one ACK; in current TCP $N = 1$ or $N = 2$. In [14], the delayed ACK mechanism is modified by allowing N to be larger than two. In addition, dynamic adaptive control of N as a function of the window size is considered.

6.1.2. TCP fairness issues

Participants: Konstantin Avrachenkov, Alberto Blanc, Natalia Osipova.

In [57], N. Osipova, A. Blanc, and K. Avrachenkov have introduced MarkMax, a new flow-aware Active Queue Management algorithm for Additive Increase Multiplicative Decreases protocols (like TCP). MarkMax sends a congestion signal to a selected connection whenever the total backlog reaches a given threshold. The selection mechanism is based on the state of large flows. Using a fluid model the authors have derived some bounds that can be used to analyze the behavior of MarkMax and compute the per-flow backlog. The paper is concluded with simulation results, using NS-2, comparing MarkMax with Drop Tail and showing how MarkMax improves both the fairness and link utilization when connections have significantly different Round Trip Times.

6.1.3. Compound TCP

Participants: Konstantin Avrachenkov, Alberto Blanc, Giovanni Neglia.

Compound TCP is one of the many new versions of TCP for high speed networks. In [81], K. Avrachenkov, A. Blanc and G. Neglia, together with D. Collange (Orange Labs, France) study the performance of Compound TCP under random losses. Markovian and deterministic models are used to derive the steady state distribution of the window and then synthetic performance metrics like average throughput and coefficient of variation of the window for an immediate comparison with TCP Reno.

6.2. Wireless communications

Keywords: *IEEE 802.11*, *IEEE 802.16e*, *MANET*, *VANET*, *WiMAX*, *Wireless LAN*, *connectivity*, *coverage*, *delay tolerant network*, *evolving files*, *mesh network*, *sensor networks*.

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Amar Azad, Anne-Elisabeth Baert, Mouhamad Ibrahim, Dinesh Kumar, Dorian Mazauric, Philippe Nain, Giovanni Neglia, Georgios Paschos, Alonso Silva.

6.2.1. Analysis of wireless access protocols

Participants: Sara Alouf, Eitan Altman, Amar Azad, Georgios Paschos.

6.2.1.1. WiMAX

Power save/sleep mode operation is the key point for energy-efficient usage of mobile devices driven by limited battery lifetime. In [29], [28], [68], S. Alouf, E. Altman and A. Azad establish a general approach for analyzing queueing models with repeated inhomogeneous vacations and apply it for the study of the power save mode defined in the IEEE 802.16e WiMAX standard. They derive the sojourn time in a $M/G/1$ queue with repeated vacations and the energy consumption when the power saving is activated as function of the protocol parameter.

6.2.1.2. VANET

In collaboration with S. Yousefi, M. Fathy (University of Science and Technology, Tehran, Iran) and R. El-Azouzi (University of Avignon, France), E. Altman has studied in [26], [25] connectivity issues in vehicular ad hoc networks (VANETs). The focus is on the expected distance of connectivity (the distance until one can forward a packet) and on the expected platoon size (the number of vehicles that are covered within that distance and can thus be reached by a given mobile). These metrics are also calculated in the case where mobile base stations are added to the model. The approach is illustrated through numerical examples based on real publicly available measurements data.

6.2.2. Power control

Participants: Eitan Altman, Konstantin Avrachenkov.

In [30], E. Altman, K. Avrachenkov and A. Garnaev (St. Petersburg State University, Russia) have studied power control in optimization and game frameworks. In the optimization framework there is a single decision maker who assigns network resources and in the game framework users share the network resources according to Nash equilibrium. The solution of these problems is based on the so-called water-filling technique, which in turn uses bisection method for solution of non-linear equations for Lagrange multipliers. In [30], the authors have provided (i) a closed-form solution to the water-filling problem, which allows one to solve it in a finite number of operations, and (ii) a closed-form solution for the Nash equilibrium in symmetric Gaussian interference game with an arbitrary number of users. A comparison between the non-cooperative and the cooperative approaches has also shown that the non-cooperative approach results in a more fair resource distribution.

The classical water filling problem is concerned with optimally assigning powers over n independent channels so as to maximize the total transmitted throughput. If each channel is associated with another mobile then it is natural to consider also the problem of fair assignment and to study tradeoffs between fairness and optimality. In [44], E. Altman, K. Avrachenkov and A. Garnaev (St. Petersburg State University, Russia) have applied the generalized α-fair resource allocation to the above mentioned problem. The object which is allocated is the transmission power, and the goal is to assign it so as to obtain α-fairness between either one of three resulting performance measures: the signal to noise ratio, a shifted version of it, or the Shannon capacity. For the case of a large number of users a variational formulation of the problem has been considered. The variational formulation allows one to design distributed resource allocation algorithms.

The same authors have considered jamming in wireless networks in the framework of zero-sum games with α-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 SNIR optimization are particular cases of the proposed more general α-fairness SNIR based utility functions. In [31], they show that the game has the unique equilibrium and investigated its properties. In particular, in several important cases they derive closed-form expressions for the equilibrium strategies and the Jain's fairness.

6.2.3. Delay and disruption-tolerant networks (DTNs)

Participants: Sara Alouf, Eitan Altman, Mouhamad Ibrahim, Philippe Nain, Giovanni Neglia.

This research has been partially supported by the IST FET grant BIONETS (see Section 8.2.2).

6.2.3.1. Evolving files in disruption tolerant networks

In [69], E. Altman and P. Nain, in collaboration with J.-C. Bermond (project-team MASCOTTE), investigate a class of distributed storage systems whose content may evolve over time. Each component or node of the storage system is mobile and the set of all nodes forms a delay tolerant (ad hoc) network (DTN). The goal of this work is to study efficient ways for distributing evolving files within DTNs and for managing dynamically their content. The authors specify to dynamic files where not only the latest version is useful but also previous ones. They however restrict to files where a file has no use if another more recent version is available. There are $N + 1$ mobile nodes including a single source which at some points in time makes available a new version of a single file F. Both the settings when nodes do not cooperate (only the source may transmit the last version of F to another node) and do cooperate (all nodes may transmit) are studied. A file management policy is a set of rules specifying when a node may send a copy of F to a node that it meets. Both myopic and state-dependent policies are considered. The objective is to find file management policies which maximize some system utility functions under a constraint on the resource consumption.

6.2.3.2. Evolutionary epidemic routing

In [67] and [75], S. Alouf and G. Neglia, together with A. Fialho (INRIA-MICROSOFT joint center, Orsay, France), I. Carreras and D. Miorandi (CREATE-NET, Italy) have presented a framework to learn in a distributed and on-line way a good forwarding policy in delay tolerant networks. The most challenging aspect of this framework concerns the estimation of the fitness of the genotype used at a node. Each node contributes to maximizing a global objective function using local knowledge. A case study is introduced to illustrate the framework. In [76], the same authors investigate the performance of the evolving protocol in terms of convergence, in particular when the node density changes over time. Validation was carried out via simulations for different generation time, mutation noise, and mutation variance.

6.2.3.3. Routing in presence of throwboxes

In collaboration with I. Carreras (CREATE-NET, Italy), M. Ibrahim and P. Nain in [83] propose and evaluate alternative strategies for routing in opportunistic disruption tolerant networks (DTNs) which include throwboxes. Throwboxes are simply fixed wireless relays with enhanced storage and energy capabilities than the mobile nodes. For DTNs extended with throwboxes, they propose five routing strategies with the ultimate goal to exploit throwboxes presence in order to minimize resource consumption at mobile nodes. Based on a Markov model, they introduce a general framework that solves recursively various performance metrics which are achieved by each strategy. Using the proposed framework, they derive insights on delay and energy trade-offs which result by adding throwboxes under each strategy.

6.2.3.4. Survey on packet dissemination techniques

In [43], M. Ibrahim, in collaboration with A. Al Hanbali (University of Twente, Netherlands), V. Simon and E. Varga (Budapest University of Technology and Economics, Hungary) and I. Carreras (CREATE-NET, Italy), classifies and surveys various packet dissemination techniques in dense and sparse mobile ad hoc networks. Using an application-based classification, they identify two classes of these techniques. The first class is conceived for applications requiring high reliability in data delivery where broadcasting is the major means used for efficient packet dissemination. The second class is conceived for delay tolerant applications where the

techniques rely on nodes mobility to perform packet routing. Based on whether future contact opportunities among the mobile nodes are scheduled, controlled, predicted or opportunistic, the authors subdivide the second class into four groups and review the various proposed techniques.

6.2.3.5. Two-hop forwarding policies in DTNs

In [70] E. Altman and G. Neglia, together with F. De Pellegrini and D. Miorandi (CREATE-NET, Italy) have studied optimal stochastic control issues in delay tolerant networks. In particular, they have derived the structure of optimal 2-hop forwarding policies. In order to be implemented, such policies require the knowledge of some system parameters such as the number of mobiles or the rate of contacts between mobiles, but these could be unknown at system design time or may change over time. For this reason adaptive policies have been designed. They combine estimation and control and are able to achieve optimal performance in spite of the lack of information. The interactions that may occur in the presence of several competing classes of mobiles have also been studied and formulated as a cost-coupled stochastic game. This game has been shown to have a unique Nash equilibrium where each class adopts the optimal forwarding policy determined for the single class problem.

6.2.3.6. Performance of relayed mobile ad hoc networks

In collaboration with T. Başar (University of Illinois at Urbana-Champaign, USA) and F. De Pellegrini (CREATE-NET, Italy), E. Altman has studied the performance of mobile ad hoc network that use relaying to make for the lack of connectivity. Mobiles thus forward packets to other mobiles when they are in the range of each other. This of course consumes resources: both energy as well as memory. In [42], optimization problems are solved that try to maximize the throughput subject to some constraints on the resources. Optimal static and dynamic policies are obtained using the Pontriagin maximum principle which is then applied to a fluid approximation model of the system.

6.2.4. Mesh networks

Participants: Eitan Altman, Dorian Mazauric, Philippe Nain, Alonso Silva.

6.2.4.1. Routing in massively dense ad hoc networks

E. Altman and A. Silva have pursued their line of research started on 2007 dedicated to studying the routing in very dense static ad hoc networks. To do so, they use a framework in which information is considered as a fluid and the topology of the network is approximated by a continuum plane. Various outstanding researchers had proposed interdisciplinary approaches for solving this problem (from both optics as well as from electrostatics). The contribution of E. Altman and A. Silva is first in providing a powerful alternative context for approaching this problem, namely that of the traffic assignment problem in road-traffic engineering. Their modeling and solution approach have appeared in [34]. Numerical solutions based on this approach and on the one previously developed (reported in 2007) have appeared in [50].

6.2.4.2. Multimedia over ad hoc networks

In [51], E. Altman studies in collaboration with R. El-Azouzi and R. El-Khoury (University of Avignon, France) real-time multimedia over multi-hop ad hoc networks which require delay bounds of the real-time application constraints. Focusing on the end-to-end delay, they develop an approximation for the loss rate of a real-time traffic which requires a delay constraint. Also proposed in this work is a cross-layer scheme from the network layer to the MAC layer to support real-time traffic.

6.2.4.3. Distributed link scheduling algorithms

In [84], D. Mazauric, J.-C. Bermond (project-team MASCOTTE) and P. Nain address the design of distributed link scheduling algorithms in wireless mesh networks. Due to interference in these networks the set of allowed calls must respect some interference constraints. In this work, the authors design several distributed (local) algorithms with constant overhead.

6.2.5. Cellular networks

Participants: Eitan Altman, Dinesh Kumar.

Over the last years, E. Altman has studied the performance uplink and downlink transmission in cellular network within contracts with FRANCE TELECOM R&D (see previous MAESTRO activity reports). Two of his works, [54] and [55] have been published in 2008. The first, in collaboration with J.-M. Kelif (Orange Labs, France), investigates multidiversity in cellular networks. Multidiversity means that a mobile connects simultaneously to more than one base station which, when the radio channel is bad, may increase the coverage of the network. The second, in collaboration with D. Barman (University of California, Riverside, USA), J.-M. Kelif (Orange Labs, France) and D. Kumar, concerns scheduling data packets over the available downlink channels.

In [18], E. Altman, T. Chahed (IT-TELECOM Sud-Paris, France) and S. E. Elayoubi (Orange Labs, France) question the "separable approach" that consists of studying separately the up and downlink, which implicitly assumes that the performance of the network is determined by the direction that has the smallest capacity. They have computed the capacity of CDMA/HSDPA by taking into account the constraints in both up and downlink and showed that the separable approach only provided a bound on the real capacity. A similar calculation taking into account both up and down link has been carried out in [49] for the WiMAX technology.

6.2.6. MIMO systems

Participant: Alonso Silva.

In [50], A. Silva studies in collaboration with R. Couillet and S. Wagner (both from NXP semiconductors) and M. Debbah (Supelec, France) the capacity limits of dense multi-antenna systems. In this paper, they derive asymptotic capacity expressions for point-to-point, broadcast and network MIMO channels by applying recent tools of random matrix theory. They find that the asymptotic capacity depends only on the ratio between the typical size of the antenna array and the wavelength. This provides useful guidelines on the achievable limits of information transfer.

This work received the *Best Student Paper Award* of the VALUETOOLS 2008 conference (Oct. 20–24, 2008, Athens, Greece).

6.2.7. Lifetime criteria in sensor networks

Participant: Anne-Elisabeth Baert.

A key criterion used to measure communication protocol efficiency in wireless sensor networks (WSNs) is the energy consumption and the lifetime of these networks. Energy is a crucial characteristic of wireless sensor networks and it is necessary to pay attention both to the energy consumption of those networks and to the distribution of energy consumption, when using communication protocols, so as to increase the lifetime of the whole network. When designing, for instance, communication protocols, it is fundamental to measure performance with a suitable metric according to the application as otherwise it would be difficult to analyze and to improve a protocol. In collaboration with J. Champ and C. Saad (University of Montpellier II, CNRS), A.-E. Baert has surveyed the existing criteria and has introduced two new criteria to measure lifetime in WSN: average node percentage and monitored interest point percentage [82].

6.3. Information systems

Keywords: *Google*, *P2P storage system*, *PageRank*, *Steiner system*, *distributed VoD systems*, *file sharing systems*.

Participants: Sara Alouf, Konstantin Avrachenkov, Anne-Elisabeth Baert, Damiano Carra, Abdulhalim Dandoush, Alain Jean-Marie, Philippe Nain, Giovanni Neglia, Danil Nemirovsky, Elena Smirnova.

6.3.1. Document ranking and clustering on the Web

Participants: Konstantin Avrachenkov, Danil Nemirovsky, Elena Smirnova.

In [85], D. Nemirovsky and K. Avrachenkov have introduced and analyzed Weighted PageRank. PageRank is a way to rank web pages taking into account hyper-link structure of the Web. PageRank provides a nice and simple method to find out ranking of Web pages exploiting hyper-link structure of the Web. However, it produces just an approximation of the ranking since the random surfer model uses just uniform distributions for all situation of choice happening during the surf process. In particular, this implies that the random surfer has no preferences. This assumption is limited by nature. Personalized PageRank was designed to solve the problem but it is still quite restricted since it assumes non-uniform preferences just at jumping to arbitrary page on the Web and non-preferring behavior when following outgoing hyper-links. Taking into account these limitations and restrictions of PageRank and Personalized PageRank, they propose Weighted PageRank which allows one to weight hyper-links according to any possible preferring behavior of a user. In particular, cluster-related weights are considered.

In [45], K. Avrachenkov and D. Nemirovsky, in collaboration with V. Dobrynin, S. K. Pham and E. Smirnova (St. Petersburg State University, Russia) have applied PageRank for clustering hyper-linked document collections, a key task in information retrieval. Most clustering methods are based on document content and do not take into account the hyper-text links. The authors have proposed a novel PageRank based clustering (PRC) algorithm which takes advantage of the hypertext structure. The PRC algorithm produces graph partitioning with high modularity and coverage. The comparison of the PRC algorithm with two content based clustering algorithms shows that there is a good match between PRC clustering and content based clustering.

6.3.2. Distributed video-on-demand systems

Participants: Anne-Elisabeth Baert, Alain Jean-Marie.

6.3.2.1. Data replication and distribution problems in a distributed VoD System

The first question addressed was that of finding the optimal replication factor of data based on the popularity of the documents [46] [78]. Optimality refers here to the average response time. Once the replication chosen, this average response time does not depend on the placement of the information, but its variance does. A family of simple placement algorithms has been studied through simulations. With those methods, it is shown that a Quality of Service guarantee on some pre-established response time can be ensured, with an error of approximately 10% [79].

The next question addressed was that of the actual optimization of the variance of download times, based on a proper block allocation scheme. The corresponding optimization problem is shown to be as difficult as finding a Steiner system. Sufficient optimality conditions are nevertheless established in some cases. Different heuristics to solve practically the problem are proposed and compared through simulation. It is shown that a random allocation is quasi-optimal [47] [80].

This research is carried out within the VOODDO project (funded by the "Multimedia" Program of the ANR), jointly with V. Boudet and X. Roche from LIRMM, CNRS/University of Montpellier II (see Section 7.3).

6.3.3. Peer-to-peer systems

Participants: Sara Alouf, Damiano Carra, Abdulhalim Dandoush, Philippe Nain, Giovanni Neglia.

6.3.3.1. Storage systems

Distributed systems using a network of peers has become an alternative solution for storing data. A. Dandoush, S. Alouf, and P. Nain study the performance of peer-to-peer storage systems (P2PSS) in terms of data lifetime and availability. In [72], two schemes for recovering lost data are modeled through absorbing Markov chains and their performance are evaluated and compared. The first relies on a centralized controller that recovers multiple losses at once, whereas the second is distributed and recovers one loss at a time. The impact of each system parameter on the performance is evaluated, and guidelines are derived for ensuring desired lifetime and/or availability of data. The authors find that, in stable environments such as laboratory networks, the distributed scheme offers a reliable, scalable and cheap storage/backup solution. However, in highly dynamic environments, it is inefficient whenever the storage overhead is kept reasonable. P2PSS with centralized-repair scheme are always efficient at the cost of maintaining a centralized authority. This study also suggests that large size fragments reduce the efficiency of the recovery mechanism.

6.3.3.2. File sharing systems

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. In [48], D. Carra and G. Neglia, together with P. Michiardi (INSTITUT EURECOM) study BitTyrant, a recently proposed strategic client. BitTyrant tries to determine the exact amount of contribution necessary to maximize its download rate by dynamically adapting and shaping the upload rate allocated to its neighbors. They evaluate in detail the various mechanisms used by BitTyrant to identify their contribution to the performance of the client and conclude that the performance gain is due to the increased number of connections established by a BitTyrant client, rather than for its subtle uplink allocation algorithm. Surprisingly, BitTyrant reveals to be altruistic and particularly efficient in disseminating the content, especially during the initial phase of the distribution process. The apparent gain of a single BitTyrant client, however, disappears in the case of a widespread adoption: results indicate a severe loss of efficiency that is analyzed in detail. In contrast, a widespread adoption of the latest version of the mainline BitTorrent client would provide increased benefit for all peers.

6.4. Game theory applied to networking

Keywords: *Nash bargaining*, *cooperative/non-cooperative games*, *evolutionary games*.

Participants: Eitan Altman, Vijay Kamble, Giovanni Neglia, Nelson Vicuna.

6.4.1. Game theory applied to general wireline networks

Participant: Eitan Altman.

6.4.1.1. Inefficiency of Nash equilibria

In [19], E. Altman in cooperation with H. Kameda (University of Tsukuba, Japan) derives general conditions implying that the Nash equilibrium of a game is not efficient in the Pareto sense. The authors then apply this framework to various frameworks for flow control: one in which the utilities are given in terms of power (ratio between throughput and delay) and another one in which they are expressed as a linear combination of a payoff for the utility and a cost per delay.

6.4.1.2. Mixed equilibrium

In networking games, there have been two main solution concepts. The Nash equilibrium that has been used in the context of finitely many atomic decision makers, and the Wardrop equilibrium used in the context of infinitely many infinitesimal (non-atomic) users, each taking its own decisions. In [20], E. Altman has studied in collaboration with H. Kameda (University of Tsukuba, Japan) and O. Pourtallier (project-team COPRIN) a combination of these concepts in which there area some atomic players that take decisions for (or on behalf of) a large number of users, and at the same time there are infinitely many non-atomic players that control their own decisions. They obtain both qualitative results on the existence and uniqueness of equilibria as well as exact expressions for the equilibria in symmetric load balancing problems.

6.4.1.3. Load balancing

In [33], E. Altman studies in collaboration with U. Ayesta and B. Prabhu (LASS-CNRS, France) optimal load balancing strategies for a multi-class multi-server processor-sharing system with a Poisson input stream, heterogeneous service rates, and a server-dependent holding cost per unit time. Specifically, they study (i) the centralized setting in which a dispatcher routes incoming jobs based on their service time requirements so as to minimize the weighted mean sojourn time in the system, and (ii) the decentralized distributed non-cooperative setting in which each job, aware of its service time, selects a server with the objective of minimizing its weighted mean sojourn time in the system. For the decentralized setting they show the existence of a potential function, which allows them to transform the non-cooperative game into a standard convex optimization problem. For the two aforementioned settings, they characterize the set of optimal routing policies and obtain a closed-form expression for the load on each server under any such policy.

6.4.2. Game theory applied to wireless networks

Participants: Eitan Altman, Vijay Kamble, Giovanni Neglia, Nelson Vicuna.

6.4.2.1. Resource allocation in wireless networks

The random matrix approach allows the derivation of simple asymptotic deterministic expressions for performance measures of various mobile networks as the number of mobiles tends to infinity. On the other side, in a game theoretical context the Wardrop equilibrium notion allows the study of Nash equilibrium behavior as the number of users grow. Combining these two asymptotic approaches, E. Altman, in collaboration with N. Bonneau, M. Debbah (Supelec, France) and A. Hjorungnes (University of Oslo, Norway), has been able to obtain in [17] the asymptotic equilibria in power allocation games with a large number of mobiles. This work was done when N. Bonneau was a Ph. D. student with MAESTRO.

6.4.2.2. Coordination games over interference channels

Consider a situation where there are several mobiles and several base stations, each base station using a different frequency band. E. Altman, V. Kamble and N. Vicuna in collaboration with H. Kameda (University of Tsukuba, Japan), T. Jimenez (University of Avignon, France) and R. Marquez (University of Los Andes, Venezuela) consider games in which a mobile has to decide how to split its power between transmissions to each base station [41] or with what probability to attempt transmission to a given base station [40]. Each mobile attempts selfishly to maximize its throughput [41] or minimize its outage probabilities [40]. They identify in their work various equilibria, one of which is also globally optimal. They identify Braess type paradoxes where by improving the channel gains, the performance at some of the equilibria degrades.

6.4.2.3. Dynamic power control games

Most work on non-cooperative power control is static: the channel gains and the available power of a mobile are fixed. E. Altman has considered various state dependent games.

In [52], E. Altman, G. He, S. Gault (MOTOROLA LABS.) and M. Debbah (Supelec, France) study the uplink of a single cell network with K users simultaneously communicating with a base station using OFDM modulation over N carriers. Users decide their power allocation based on one three possible Channel State Information (CSI) levels: complete, partial and statistical. The optimal solutions for maximizing the average capacity with complete and statistical knowledge are known to be the water-filling game and the uniform power allocation, respectively. They study the problem in the partial knowledge case. They formulate it as a strategic game, where each player (user) selfishly maximizes his own average capacity. The information structure that is considered is such that each player, at each time instant, knows his own channel state, but does not know the state of other players. They investigate the existence and uniqueness of Nash equilibrium. They find the optimal solution for the symmetric case considering two positive channel states, and solve the optimization problem for any L states.

In [53], the same authors describe a power allocation strategy for fixed constellation over parallel Gaussian channels in the multiuser context. The criterion under consideration is mutual information, given arbitrary input distributions over users and over subcarriers. The algorithm achieves, with very low complexity, the multi-user aggregate sum mutual information upper bound. The algorithm is based on an iterative Mercury/waterfilling procedure which is an extension to the waterfilling approach. Moreover, the authors extend the framework to a decentralized scenario using a linear approximation of the MMSE function. They show, in particular that each user can, under certain assumptions, independently determine the power allocation without knowing the channel information of other users. Simulation results validate the theoretical claims.

In collaboration with S. Sarkar (University of Pennsylvania, USA), R. El-Azouzi and Y. Hayel (University of Avignon, France), E. Altman investigates in [58] a game in which n channels are available to a mobile. The authors consider some adversarial node that can prevent the mobile to obtain the information on the state of k out of the n channels. Using a zero-sum Bayesian game model, they answer the question of which state-dependent jamming policy is the most harmful and what is the best way for the other mobile to react: which channel should it choose knowing the statistics of those that the jammer prevents it to know and knowing the states of the others.

In a second type of state-dependent game [56], E. Altman, in collaboration with I. Menache (Technion, Israel) assumes that the battery energy is finite, so that power control decisions at a given time have an impact on the remaining energy later. The goal of a mobile is to maximize the expected amount of information it an transfer during its life time. Theses authors formulate and solve this optimization problem.

6.4.2.4. 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. In [86], G. Neglia, together with I. Tinnirello and L. Giarrè (University of Palermo, Italy) has studied the interaction of selfish nodes in two different scenarios: in the first one mobile stations are simply interested to maximize their upload rate to a single Access Point (AP); in the second one, they are also interested in their downlink rate. The work highlights the poor performance originated by selfish behaviors and studies the role of the AP in WiFi networks in infrastructure mode. Simple changes to AP functionalities can be introduced to design the game in order to achieve optimal global performance at Nash equilibrium.

6.4.3. Evolutionary games

Participant: Eitan Altman.

This research has been partially funded by the IST FET grant BIONETS (see Section 8.2.2).

Evolutionary games consist of a large population of individual players. There are many local interactions among members of the population where each local interaction involves a limited small number of individuals that are randomly selected. The solution concept is the ESS (Evolutionary Stable Strategy) which is characterized by robustness against deviations of a whole fraction (possibly small) of individuals (these deviations are called mutations). E. Altman has introduced in collaboration with Y. Hayel, H. Tembine and R. El-Azouzi (University of Avignon, France) a new class of evolutionary games in which each individual may be described by the state of a Markov chain, where the action chosen by an individual during a local interaction (together with the states and actions of each individual involved in the interaction) not only determines its fitness but also the transition of the individual's Markov chain. Unlike standard evolutionary games, an individual tries to maximize not just its instantaneous fitness but the total accumulated fitness during his lifetime, or the expected fitness averaged during its lifetime. E. Altman and Y. Hayel have used this framework in [37] to study a large population of mobiles forming a sparse ad hoc network and competing with each other for the access to the radio channel. Theoretical foundations of this approach were laid in in [38] and [39]. Extensions of these papers have appeared in [60] and [62].

In [63], E. Altman, jointly with H. Tembine, R. El-Azouzi (University of Avignon, France) and W. H. Sandholm (University of Madison, USA) has introduced a new class of spatial evolutionary game models in which individuals take decisions concerning migration from one area to another one, and other actions within the local area where they are. They applied this framework to cellular networks in which location decisions may represent not only the physical locations of the individual but also the physical location of the base station. The migration represents handover decisions.

In [36], [61], E. Altman in collaboration with H. Tembine, R. El-Azouzi and Y. Hayel (University of Avignon, France) uses evolutionary games to study several games occurring in wireless networks such as access games and scheduling games (in the context of WiMAX). To this end, they extend the framework of evolutionary games so as to cover the situation where there is a random number of interacting players. This extension makes the framework suitable for access control games, which are addressed in [61].

So far the setting of evolutionary games has been used in MAESTRO to tackle access or power control problems in wireless networks. An exception to that is [35] in which E. Altman studies in cooperation with H. Tembine, Y. Hayel and R. El-Azouzi (University of Avignon, France) the evolution of competing flow control protocols. In this work models of population dynamics (such as the replicator dynamics) are considered to understand under what conditions can one expect different variants of TCP protocols to coexist, and what fraction of users should be using each type. In [35], the evolution of congestion control protocols is investigated in an

evolutionary context in which delays exist in updating protocol versions; these correspond to the time needed to change the TCP version on one's computer (or the time it takes to change to a new computer). Stability issues are also addressed in this work as well as possible oscillatory behavior due to the introduction of these delays; the analysis is done by using the theory of delayed differential equations.

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

Keywords: *Cost-coupled stochastic games*, *discriminatory processor sharing queue*.

Participants: Eitan Altman, Konstantin Avrachenkov, Natalia Osipova.

6.5.1. Advances in game theory

Participants: Eitan Altman, Konstantin Avrachenkov.

6.5.1.1. Theory of cost-coupled stochastic games

In [13], E. Altman, K. Avrachenkov, N. Bonneau (former MAESTRO Ph. D. student), M. Debbah (Supelec, France), R. El Azouzi (University of Avignon, France) and D. S. Menasche (University of Massachusetts, USA) have developed the theory of cost-coupled stochastic games. This class of games model a weak interaction between agents, each of which having its own associated Markov chain which it controls. The interaction between the agents appears through the utilities or costs of each player, which is a function of the state of all Markov chains as well as of the actions used by all agents. This framework has many applications which these authors have studied and published in previous years, and which have motivated this theoretical work.

6.5.2. Branching processes with queueing applications

Participant: Eitan Altman.

In the last several years, E. Altman has been developing the theory of branching processes with non-Markovian immigration process, and has been applying it to a large number of queueing problems: polling with correlated vacations, the infinite server with correlated arrivals and more. Branching processes can be written in the form $X_{n+1} = A_n(X_n) + B_n$ where B_n is the immigration and A_n is a subordinator (non-decreasing Lévy process) with the following central properties: (i) it is infinitely divisible and (ii) it has independent increments. In [77], E. Altman extends this class of processes by dropping the requirement of independent increments in the process $\{A_n\}$. The equations that define this new class are called. "semi-linear stochastic difference equations". Explicit expressions for the first moments of X_n in steady-state under the weak assumption that the process $\{B_n\}$ is stationary and ergodic are derived.

6.5.3. Advances in queueing theory

Participants: Konstantin Avrachenkov, Natalia Osipova.

6.5.3.1. Stochastic scheduling

In [23], N. Osipova studies the Batch Processor-Sharing queueing model with a hyper-exponential service time distribution and Poisson batch arrival process. In the case of the hyper-exponential service time distribution, she derives an analytical expression for the expected conditional response time function and obtains an alternative proof of its concavity with respect to the service time. She then applies these results to the Two Level Processor-Sharing (TLPS) model with the hyper-exponential service time distribution and computes the expected response time for the TLPS model. In contrast with the BPS queue, the expected conditional response time function is not a concave function in the TLPS model.

In [73], N. Osipova investigates the Discriminatory Processor Sharing (DPS) policy. Under the DPS policy jobs are organized in classes, which share a single server. The capacity that each class obtains depends on the number of jobs in all classes and is controlled by the vector of weights. Varying DPS weights it is possible to give priority to different classes at the expense of others, to control their instantaneous service rates and to optimize different system characteristics such as mean sojourn time. So, the proper weight selection is an important task, which is not easy to solve because of the model's complexity. In this work, N. Osipova compares the performance of two DPS policies with different weight vectors. She establishes the monotonicity of the expected sojourn time of the system depending on the weight vector under certain technical conditions on the system. These conditions imply that the expected job sizes should be "very different" (in a sense explained in the paper). These restrictions can be overcome by setting the same weights for classes which have "close" expected job sizes. The condition on expectations is a sufficient but not a necessary condition. It becomes less strict when the system is less loaded.

6.5.3.2. Retrial networks

In [16], K. Avrachenkov and U. Yechiali (University of Tel Aviv, Israel) have studied retrial networks with finite buffers and their applications to Internet traffic. Up to now the majority of Internet routers use a simple drop-tail strategy. The rate at which a user injects data into the network is determined by TCP. However, most connections in the Internet consist only of few packets, and TCP does not really have an opportunity to adjust the sending rate. Thus, the data generated by short TCP connections appears to be some uncontrolled stochastic process. In the present work, the authors model the interaction of the data generated by short TCP connections with the help of a network with finite buffers. The framework of retrial queues and networks appears to be an adequate approach for this problem. The effect of packet retransmission becomes essential when the network congestion level is high. The authors consider several benchmark retrial network models. In some particular cases, explicit analytic solution can be derived. If the analytic solution is not available or too entangled, the authors suggest to use a fixed point approximation scheme. In particular, they consider a network of one or two tandem $M/M/1/K$ queues with blocking and $M/M/1/1$ retrial (orbit) queue. They authors explicitly solve the models with particular choices of K, derive stability conditions, and present several graphs based on numerical results.

7. Contracts and Grants with Industry

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

MAESTRO participates in the Research Actions (RA) "Semantic Networking" (SEMNET) and "Self Optimization in Wireless Networks" (SELFNET), two of the three RAs of the INRIA ACATEL-LUCENT joint laboratory. These RAs started on Jan. 1st 2008 and will last for four years.

Pascale Vicat-Blanc Primet, head of INRIA project-team RESO is the coordinator for INRIA of the RA SEMNET and Bruno Gaujal, head of INRIA project-team MESCAL is the coordinator for INRIA of the RA SELFNET. ALTCATEL-LUCENT coordinators of RAs SEMNET and SELFNET are Ludovic Noirie and Laurent Thomas, respectively.

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

7.1.1. Research Action "Semantic Networking"

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Damiano Carra, 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 filled in 2008 (inventors for INRIA: S. Alouf, K. Avrachenkov, D. Carra, P. Nain).

E. Altman participates with P. Vicat-Blanc Primet (project-team RESO) in the supervision of the Ph. D. thesis of Dinil Mon Divakaran (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. Research Action "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. ANR Télécommunications WINEM (2007–2009)

Participants: Sara Alouf, Eitan Altman, Amar Azad, Georgios Paschos.

This project, called WINEM, for "WiMAX Network Engineering and Multihoming", started on Jan. 1st 2007 and will last for 3 years. It aims at engineering and evaluating solutions for the issues left open in the WiMAX standard, such as quality of service and service differentiations. Other issues are related to mobility management, resource allocation, multihoming, pricing, cross-layer optimization and performance tuning. The project partners are: FRANCE TELECOM R&D, INSTITUT TELECOM (ENST Bretagne and INT), INRIA (INRIA project-teams DYONISOS and MAESTRO), INSTITUT EURECOM, LIA (University of Avignon) and Motorola.

S. Alouf is the coordinator for INRIA.

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

7.3. ANR Multimedia VOODDO (2008–2010)

Participants: Anne-Elisabeth Baert, 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 architecture of this infrastructure, named "Grid Delivery Network" has been defined by VODDNET. Challenging problems of data distribution and real-time control of the platform are at the heart of this project.

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 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 Jan. 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), Prof. R. Sundaresan, Prof. V. Sharma and Prof. A Chokalingam. Two other foreign teams are TIFR Mumbay with Prof. V. Borkar and the University of Pennsylvania with Prof. 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.

8.1.2. Australian Research Council Discovery Grant (2007-2009)

Participant: Konstantin Avrachenkov.

This is a bilateral collaboration between MAESTRO team and the School of Mathematics of the University of South Australia. The topic of this collaboration is the development of new perturbation methods for solving singular operator equations with applications to Statistics and Complex System Analysis. K. Avrachenkov is the coordinator of this project.

8.2. European initiatives

8.2.1. ICT STREP ECODE (2008-2011)

Participants: Sara Alouf, Konstantin Avrachenkov, Giovanni Neglia, Natalia Osipova.

MAESTRO is a partner of the ICT European STREP Project ECODE on “Experimental COgnitive Distributed Engine”. S. Alouf is the coordinator for MAESTRO.

ECODE is a 3-year STREP project (running from Sept. 2008 to Aug. 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/.

8.2.2. IST FET IP BIONETS (2006-2009)

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Giovanni Neglia, Alonso Silva.

MAESTRO is a partner of the IST FET European Integrated Project BIONETS on “BIOlogically-inspired autonomic NETworks and Services”. E. Altman is the coordinator of the work package on “Paradigm Collection and Foundations”.

BIONETS is a project belonging to the IST FET Proactive Initiative Program on “Situated and Autonomic Communication”. There are sixteen partners involved and MAESTRO, together with INRIA project-team OASIS and colleagues from INSTITUT EURECOM, is one of them. BIONETS is planned for four years and started on Jan. 1st 2006.

BIONETS specializes on the design of protocols that will allow evolution of services over a self-organizing wireless network that contains a huge amount of cheap sensors, as well as a limited number of intelligent terminals. The project proposes an inter-disciplinary strategy for designing such networks (called bionets) by using methods and tools from biology, physics, economics. MAESTRO’s task is to collect such tools and to adapt them to BIONETS.

http://www.bionets.eu/.

8.2.3. Network of Excellence: EuroFGI (2007-2008) and EuroNF (2008-2009)

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

MAESTRO is a member of the Network of Excellence (NoE) EUROFGI/NF which is a continuation of the EURONGI Network of Excellence on "Design and Engineering of the Next Generation Internet, Towards Convergent Multi-Service Networks" (see 2004-2007 MAESTRO activity reports).

http://euronf.enst.fr/.

8.2.4. EGIDE ECO-NET Project "Game theory for Wireless Networks" (2008)

Participants: Konstantin Avrachenkov, Giovanni Neglia.

In this EGIDE ECO-NET project, MAESTRO collaborates with St. Petersburg State University and Erevan State University on the application of game theory methods to wireless networks. A number of exchange visits have taken place among the three institutions. K. Avrachenkov is the coordinator of this project.

8.3. National initiatives

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

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

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: Vahan Avetisyan (Yerevan State University, Armenia 08/03/08–08/23/08),
Urtzi Ayesta (LAAS, Toulouse, 06/04/08-06/07/08),
Jocelyne Elias (Polytechnic School of Milan, Italy, 10/16/08–01/12/09),
Dieter Fiems (Gent University, Belgium) 09/01/08–10/10/08),
Andery Garnaev (St. Petersburg State University, Russia, 03/23/08–04/05/08 and 09/07/08–09/17/08),
Jean-Yves Le-Boudec (EPFL, Switzerland, 06/23/08–06/29/08),
Fabio Martignon (University of Bergamo, Italy, 10/16/08–01/12/09),
Daniele Miorandi (CREATE-NET, Trento, Italy, 05/26/08-05/30/08),
Leon Petrosyan (St. Petersburg State University, Russia, 08/04/08–08/19/08),
Georg Post (ALCATEL-LUCENT BELL LABS, France, 10/16/08–10/17/08),
Alexei Piunovsky (University of Liverpool, UK, 06/02/08–06/30/08),
Ilenia Tinnirello (University of Palermo, Italy, 09/30/08–10/03/08).

America: Tamer Başar (University of Illinois at Urbana-Champaign, USA, 03/13/08–03/22/08), Marwan Krunz (University of Arizona, Tucson, USA, 06/30/08–07/22/08), Ravi Mazumdar (University of Waterloo, Canada, 12/15/08–12/16/08).

Maghreb, Middle-East: Gideon Weiss (Tel Aviv University, Israel, 05/19/08–05/21/08), Uri Yechiali (Tel Aviv University, Israel, 04/20/08–04/28/08).

Asia: Vivek Borkar (TATA Institute of Fundamental Research, Bumbai, India, 09/07/08-10/02/08), Anurag Kumar (IISc, Bangalore, India, 06/03/08–06/13/08), Rajesh Sundaresan (IISc, Bangalore, India, 05/06/08–05/25/08).

8.5. Visits of Maestro staff to other research institutions

E. Altman within the Associate Team DAWN, visited IISc (collaboration with Profs. A. Kumar, V. Sharma and Dr. R. Sundaresan, 01/26/08–02/02/08, Bangalore, India), and PENN State University in Pennsylvania (visit of Prof. S. Sarkar, 07/25/08–08/1/08). He visited Dr. I. Menache at MIT, Boston, Massachusetts, USA (Aug. 2–4, 2008) and the Technion, Haifa, Israel (11/30/08–12/6/08).

P. Nain visited Prof. D. Towsley and the Computer Networks group at the University of Massachusetts during February 5–12, 2008.

G. Neglia visited the Computer Networks group at the University of Massachusetts from Dec. 1st until Dec. 22nd 2008.

N. Osipova visited Dr. U. Ayesta at LAAS, Toulouse, France (Mar. 2–10, 2008) and the Advanced Communication Networks group at the Centrum Wiskunde & Informatica (CWI), The Netherlands, from Mar. 17th until Apr. 15th 2008.

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) and of *Journal of Discrete Event Dynamic Systems* (JDEDS).

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

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

S. Alouf was a program committee member of the following conferences:

- ACM SIGMETRICS 2008 (June 2–6, 2008, Annapolis, Maryland, USA).
- IEEE INFOCOM 2009 (Apr. 19–25, 2009, Rio de Janeiro, Brazil).
- 24th ACM Symposium on Situated Autonomic Computing (SAC 2009) track on Computer Networks (Mar. 8–12, 2009, Honolulu, Hawaii, USA).
- ACM SIGMETRICS 2008 Student Thesis Panel (June 3, 2008, Annapolis, Maryland, USA).
- 9th Workshop on Performance Evaluation (AEP9), (June 1–4, 2008, Aussois, France).

E. Altman was a program committee member of the following conferences:

- IEEE INFOCOM 2009 (Apr. 19–25, 2009, Rio de Janeiro, Brazil).
- IFIP Networking 2008 (May 5–9, 2008, Singapore).
- 13th Symposium of International Symposium on Dynamic Games and Applications (ISDGA 2008) (June 30 – July 3, 2008, Wroclaw, Poland).
- 7th International Conference on Ad Hoc Networks and Wireless (AdHocNow 2008) (Sept. 12–14, 2008, Sophia-Antipolis, France).
- 2nd International Conference on Game Theory and Management (GTM 2008) (June 26–27, 2008, St. Petersburg, Russia).
- 2nd International Workshop on Game Theory in Communication Networks (GameComm 2008) (Oct. 20, Athens, Greece).
- 2nd Workshop on NS-2 (WNS2 2008) (Oct. 23–24, 2008, Athens, Greece).

K. Avrachenkov was a program committee member of the following conferences:

- 16th IEEE International Conference on Networks (ICON 2008) (Dec. 12–14, 2008, New Delhi, India).
- 15th IEEE International Conference on Telecommunications (ICT 2008) (June 16–17, 2008, St. Petersburg, Russia).
- 2nd International Workshop on Wireless Networks: Communication, Cooperation and Competition (WNC3 2008) (Apr. 4th, 2008, Berlin, Germany).
- International Workshop on Multiple Access Communications (MACOM 2008) (June 17–18, 2008, St. Petersburg, Russia).

A. Jean-Marie was a program committee member of the following conferences:

- ACM SIGMETRICS/Performance 2009 (June 15–19, 2008, Seattle, Washington, USA).
- 10th Workshop on Mathematical performance Modeling and Analysis (MAMA 2008) (June 2, 2008, Annapolis, Maryland, USA).

P. Nain was a program committee member of the following conferences:

- IEEE INFOCOM 2009 (Apr. 19–25, 2008, Rio de Janeiro, Brazil) (TCP Area Chair).
- 10th Workshop on Mathematical performance Modeling and Analysis (MAMA 2008) (June 2, 2008, Annapolis, Maryland, USA).
- Rescom 2009 (Summer School on Networking) (June 7–13, 2009, Royan, France) (Member of scientific committee).

G. Neglia was a program committee member of the following conferences:

- IEEE INFOCOM 2009 (Apr. 19–25, 2008, Rio de Janeiro, Brazil).
- 2nd International Conference on Autonomic Computing and Communication Systems (Autonomics 2008) (Sept. 23–25, 2008, Turin, Italy.
- 2nd Euro-NF Workshop on Network Control and Optimization (NET-COOP 2008) (Sept. 8–10, 2008, Paris, France).

9.1.3. Conferences, meetings and tutorial organization

S. Alouf was the Workshops co-chair of the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008) (Oct. 20–24, 2008, Athens, Greece).

E. Altman participated in the Steering Committee of the following conferences:

- *6th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks* (WiOpt 2008) (Mar. 31–Apr. 4, 2008, Berlin, Germany).

- *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008) (Oct. 20–24, 2008, Athens, Greece).
- *2nd Euro-NF Workshop on Network Control and Optimization* (NET-COOP 2008) (Sept. 8–10, 2008, Paris). In that conference, E. Altman was also the Co-Chair of the program committee.

K. Avrachenkov was the Co-Chair of the *3rd International Workshop on Tools for Solving Structured Markov Chains* (Oct. 20, 2008, Athens, Greece).

E. Deriche was the Webmaster of the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008) along with a member of the organizing committee of this conference and of its associated workshops *GameComm, Modenets, SMCTools, Inter-Perf* and *WNS2* (Oct. 20–24, 2008, Athens, Greece).

A. Jean-Marie was the Tutorial Chair of *QEST 2008* (Sept. 14-17, 2008, St Malo, France).

G. Neglia was the Co-Chair of the *3rd Workshop on Interdisciplinary Systems Approach in Performance Evaluation and Design of Computer and Communication Systems* (Inter-Perf 2008) (Sept. 24, Athens, Greece).

9.1.4. Participation in thesis committees

E. Altman was a member of the HDR thesis of Merouane Debbah (Sept. 12, 2008, Supelec), the Ph. D. thesis committee of Dinesh Kumar (Nov. 26, 2008, University of Nice Sophia Antipolis) as thesis advisor, and of the Ph. D. thesis committee of Ralph El-Khoury (Sept. 25, 2008, University of Avignon).

A. Jean-Marie participated in the Ph. D. thesis committees of Ralph El-Khoury (Sept. 25, 2008, University of Avignon) and Thierry Peyre (Dec. 9, 2008, University of Avignon).

P. Nain was a member of the Ph. D. thesis committees of Thomas Begin (Dec. 5, 2008, Paris 6) as reviewer, of Mouhamad Ibrahim (Nov. 14, 2008, University of Nice Sophia Antipolis) as thesis advisor, and of Sonja Petrovic (May 27, 2008, University of Nice Sophia Antipolis) as thesis co-advisor.

9.1.5. Ph. D. theses defended in 2008

The following Ph. D. theses were defended in 2008:

M. Ibrahim Ph. D. Thesis from the University of Nice Sophia Antipolis: “Routing and Performance Evaluation of Disruption Tolerant Networks” [11]. Graduation on Nov. 14, 2008. Advisor: P. Nain.

D. Kumar Ph. D. Thesis from the University of Nice Sophia Antipolis: “Optimization and Control in Wireless and Computer Networks” [12]. Graduation on Nov. 26, 2008. Advisor: E. Altman.

9.1.6. Research administration

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

A.-E. Baert

- is a member of the Recruiting Committee (Commission de Spécialistes) in Computer Science at the University of Montpellier II.
- was in charge of the Master in Combinatorics, Algorithms, Security and Administration of Networks at the University of Montpellier II.

A. Jean-Marie

- is the scientific coordinator of INRIA activities in Montpellier.
- 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.

- is a member of the Recruiting Committee (Commission de Spécialistes) in Computer Science at the University of Montpellier II.
- is a member of the Steering Committee of the GDR RO, a national research initiative on Operations Research sponsored by the CNRS.
- is a member of the Best Thesis Award Committee of SPECIF, the French Society for Education and Research in Computer Science.

P. Nain

- is the Scientific Deputy of the Research Center of INRIA Sophia Antipolis - Méditerranée and the Chair of its Project-team Committee (since Sept. 1st, 2007).
- is Head of project-team MAESTRO.
- is a member of the management of the Research Center of INRIA Sophia Antipolis - Méditerranée.
- is a member of the Evaluation Committee of INRIA.

9.1.7. Miscellaneous (nominations, awards, etc.)

- A. Silva, received the Best Student Paper Award of the VALUETOOLS 2008 conference (Oct. 20–24, 2008, Athens, Greece) for his paper entitled "The Space Frontier: Physical Limits of Multiple Antenna Information Transfer", coauthored with R. Couillet, S. Wagner and M. Debbah.
- 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, 2009).

9.2. Teaching

A.-E. Baert taught courses in the Master in Computer Science of the University of Montpellier II on "Performance Evaluation" (6H), "Quality of Service in Networks" (27H), "Random Discrete Structures" (27H) and "Metrology and Quality of Services" (68H). She participated in the course on "Communication and Networks" of the Master in Computer Science of the University of Montpellier II (30H).

A. Dandoush was in charge of the course on "Unix System: Architecture and Advanced Programming" in the Bachelor Program in Computer Science at the IUT of Nice Sophia Antipolis (22H of theory, 75H of practice).

M. Ibrahim and G. Neglia taught the course on "Advanced Simulations with NS-2 2008" in the Master STIC (Sciences et Technologies de l'Information et de la Communication) of the University of Nice Sophia Antipolis (15H).

A. Jean-Marie taught a course on "Random Discrete Structures" (12H), and one on "Metrology and Quality of Service for Networks" (12H), both in the Master in Computer Science of the University of Montpellier II. He was invited to give a short course on "Network Calculus" at the University of Valparaiso, Chile.

D. Mazauric participated as a teaching assistant (moniteur) in the courses on "Functional Programming" (18H) and on "Algorithms and complexity" (10H) in the Bachelor Program on Computer Science at the University of Nice Sophia Antipolis and at the IUT of Nice Sophia Antipolis, respectively.

D. Nemirovsky taught the course on "Mathematical Modeling in Networks" at St. Petersburg State University (15H of lecture, 2H of homework).

9.3. Participation in scientific events

9.3.1. Technical program commitee meetings

IEEE INFOCOM 2009, Dec. 13, 2008, New York City, New York, USA: attended by: P. Nain and G. Neglia.

ACM SIGMETRICS 2008, Jan. 25–26, 2008, New York City, New York, USA: attended by: S. Alouf.

9.3.2. Invited talks

E. Altman was a keynote speaker at the *First IEEE International Workshop on Cognitive Radio and Networks* (CRNETS 2008, Sept. 15, 2008, Cannes, France) held in conjunction with the *19th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications* (PIMRC 2008).

G. Neglia gave invited talks at *Deutsche Telekom Laboratories Recruiting Symposium* (Mar. 29, 2008, Berlin, Germany) and at the *Telecommunications Colloquium Series of Delft University* (Jan. 21, 2008, Delft, The Netherlands).

A. Silva gave a presentation at *University of Paris Dauphine* (Nov. 6, 2008, Paris, France).

9.3.3. Conferences and workshops

S. Alouf gave a presentation at the *5th International Conference on the Quantitative Evaluation of SysTems* (QEST 2008, Sept. 14–17, 2008, Saint-Malo, France).

E. Altman gave presentations at the *6th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks* (WiOpt 2008, Mar. 31 – Apr. 4, 2008, Berlin, Germany) including the *Physcomnet 2008* one day workshop, the *13th International Symposium on Dynamic Games and Applications*, (ISDGA 2008, June 30–July 3, 2008, Wroclaw, Poland), and the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008, Oct. 20–24, Athens, Greece) including the *Interperf 2008* one day workshop.

A. Azad presented a poster at the *International Conference on Measurement and Modeling of Computer Systems* (ACM SIGMETRICS 2008, June 2–6, 2008, Annapolis, Maryland, USA). He attended the *2nd Euro-NF Workshop on Network Control and Optimization* (NET-COOP 2008, Sept. 8–10, 2008, Paris, France).

K. Avrachenkov gave a presentation at the *27th IEEE Conference on Computer Communications* (IEEE INFOCOM 2008, Apr. 14–17, Phoenix, Arizona, USA). He attended the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008, Oct. 20–24, 2008, Athens, Greece) and the associated workshop *SMCTools 2008*.

D. Carra gave a presentation at the *8th IEEE International Conference on Peer-to-Peer Computing* (P2P 2008, Sept. 8–11, 2008, Aachen, Germany).

A. Jean-Marie gave a presentation at the *Symposium on Perspectives in Modeling and Performance Analysis of Computer Systems and Networks* (Model35, Apr. 2–3, 2008, Rocquencourt, France).

P. Nain attended the *Symposium on Perspectives in Modeling and Performance Analysis of Computer Systems and Networks* (Model35, Apr. 2–3, 2008, Rocquencourt, France) and the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008, Oct. 20–24, Athens, Greece).

G. Neglia attended the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008, Oct. 20–24, 2008, Athens, Greece) and the associated workshops *GameComm 2008* and *Inter-Perf 2008*, and attended the *ARC Popeye Seminar* (May 21–23, 2008, Grenoble, France).

D. Nemirovsky presented a poster at the *ACM SIGIR 2008 Workshop: Learning to Rank for Information Retrieval* (July 24, Singapore).

N. Osipova gave a presentation at the *15th International Conference on Telecommunications* (ICT 2008, June 16–17, 2008, St. Petersburg, Russia).

A. Silva gave presentations at the *Inter-Perf 2008* workshop held in conjunction with the *3rd International Conference on Performance Evaluation Methodologies and Tools* (VALUETOOLS 2008, Oct. 20-24, Athens, Greece) (2 papers presented), *the 7th International Conference on Ad Hoc Networks and Wireless*, (ADHOC-NOW 2008, Sept. 10-13, 2008, Sophia-Antipolis, France), *Workshop on Transport, Optimization, Equilibrium in Economics*, (July 14–18, 2008, Vancouver, Canada), *9ème congrès de la Société Française de Recherche Opérationnelle et d'Aide à la Décision* (ROADEF 2008, Feb. 25–28, 2008, Clermont-Ferrand, France).

9.3.4. Seminars and meetings related to projects

ANR WINEM open seminar, Feb. 11, 2008, Paris, France: attended by: S. Alouf, E. Altman, and A. Azad; presentation by: E. Altman.

SAC-FIRE Workshop, Mar. 4–5, 2008, Turin, Italy: attended by: S. Alouf.

2nd review of BIONETS, Mar. 6–7, 2008, Turin, Italy: attended by: S. Alouf and E. Altman.

Joint workpackage meeting of BIONETS, Apr. 23–25, 2008, Berlin, Germany: attended by: S. Alouf.

2nd ARC POPEYE seminar, May 21–23, 2008, Grenoble, France: attended by: E. Altman, A. Azad, A. Jean-Marie, V. Kamble, G. Neglia, A. Silva; presentations by: E. Altman, A. Azad, A. Jean-Marie, V. Kamble, A. Silva.

1st seminar of the INRIA ACATEL-LUCENT joint laboratory, July 1–2, 2008, Paris, France: attended by S. Alouf, K. Avrachenkov, D. Carra, and P. Nain.

Kick-off meeting of ECODE, Sept. 1–3, 2008, Antwerpen, Belgium: attended by: S. Alouf and G. Neglia.

Meeting of BIONETS sub-project 1, Oct. 9–10, 2008, Pisa, Italy: attended by: G. Neglia.

Meeting of ANR WINEM, Dec. 5, 2008, Avignon, France: attended by: S. Alouf and A. Azad; presentation by: A. Azad.

9.3.5. Schools and students workshops

Euro-NGI Joint Ph. D. Course, Mar. 10–14, 2008, Valencia, Spain: attended by A. Dandoush. Course title "Main Trends in Teletraffic Modelling".

9th Workshop on Performance Evaluation, June 1–4, 2008, Aussois, France: attended by: S. Alouf, A. Dandoush, and N. Osipova; presentations by: A. Dandoush and N. Osipova

ICAR 2008 Summer School, Aug. 25–29, 2008, Nice, France: attended by: A. Dandoush, D. Nemirovsky, and N. Osipova.

1st Euro-NF summer school, Sept. 15–19, 2008, Warsaw, Poland: attended by: D. Nemirovsky.

10. Bibliography

Major publications by the team in recent years

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[3] E. ALTMAN, D. FIEMS. *Expected waiting time in symmetric polling systems with correlated vacations*, in "Queueing Systems – Theory and Applications", vol. 56, n^o 3-4, Aug. 2007, p. 241–253.

[4] K. AVRACHENKOV, U. AYESTA, P. BROWN, R. N. QUEIJA. *Discriminatory Processor Sharing Revisited*, in "Proc. of IEEE Infocom 2005, Miami, FL, USA", vol. 2, Mar. 13–17, 2005, p. 784–795.

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[6] F. CLÉVENOT-PERRONNIN, P. NAIN, K. W. ROSS. *Stochastic Fluid Model for Cache Clusters*, in "Performance Evaluation", vol. 59, n^o 1, Jan. 2005, p. 1–18.

[7] C. FIGUIÈRES, A. JEAN-MARIE, N. QUÉROU, M. TIDBALL. *Theory of Conjectural Variations*, World Scientific Publishing, Feb. 2004.

[8] R. GROENEVELT, P. NAIN, G. KOOLE. *Message Delay in Mobile Ad Hoc Networks*, in "Performance Evaluation", Proc. of Performance 2005, Juan-les-Pins, France, Oct. 3–7, 2005, vol. 62, n^o 1-4, 2005, p. 210–228.

[9] A. KUMAR, E. ALTMAN, D. MIORANDI, M. GOYAL. *New Insights From a Fixed-Point Analysis of Single Cell IEEE 802.11 WLANs*, in "IEEE/ACM Transactions on Networking", vol. 15, n^o 3, June 2007, p. 588–601.

[10] P. NAIN, D. TOWSLEY, B. LIU, Z. LIU. *Properties of Random Direction Models*, in "Proc. of IEEE Infocom 2005, Miami, FL, USA", vol. 3, Mar. 13–17, 2005, p. 1897–1907.

Year Publications

Doctoral Dissertations and Habilitation Theses

[11] M. IBRAHIM. *Routing and Performance Evaluation of Disruption Tolerant Networks*, Ph. D. Thesis, University of Nice Sophia Antipolis, Nov. 14, 2008.

[12] D. KUMAR. *Optimization and Control in Wireless and Computer Networks*, Ph. D. Thesis, University of Nice Sophia Antipolis, Nov. 26, 2008.

Articles in International Peer-Reviewed Journal

[13] E. ALTMAN, K. AVRACHENKOV, N. BONNEAU, M. DEBBAH, R. EL-AZOUZI, D. S. MENASCHE. *Constrained Cost-Coupled Stochastic Games with Independent State Processes*, in "Operations Research Letters", vol. 36, n^o 2, Mar. 2008, p. 160–164.

[14] E. ALTMAN, T. BAŞAR, N. MALOUCH. *The Role of Information Update in Flow Control*, in "IEEE Transactions on Communications", vol. 56, n^o 8, Aug. 2008, p. 1331–1342.

[15] A. AL HANBALI, P. NAIN, E. ALTMAN. *Performance of ad hoc networks with two-hop relay routing and limited packet lifetime (extended version)*, in "Performance Evaluation", vol. 65, n^o 6-7, June 2008, p. 463–483.

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[24] V. RAMAIYAN, A. KUMAR, E. ALTMAN. *Fixed Point Analysis of Single Cell IEEE 802.11e WLANs: Uniqueness and Multistability*, in "IEEE/ACM Transactions on Networking", vol. 16, n^{o} 5, Oct. 2008, p. 1080–1093.

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[27] H. ZHANG, G. NEGLIA, D. TOWSLEY, G. LO PRESTI. *Stability and Efficiency of Unstructured File Sharing Networks*, in "IEEE Journal on Selected Areas in Communications", vol. 26, n^{o} 7, Sept. 2008, p. 1284–1294.

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