INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team maestro

Models for Performance Analysis and Control of Networks

Sophia Antipolis

THEME COM

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2. Overall Objectives

MAESTRO is a joint project-team of INRIA, CNRS and the University of Montpellier II (through the LIRMM laboratory), based in Sophia Antipolis and in Montpellier. It is concerned with the modeling, performance evaluation, optimization and control of 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 2004 have focused on the following issues:

- performance evaluation of wireless, mobile, ad hoc and sensor networks, in particular within a research grant from FRANCE TELECOM R&D and the support of CEFIPRA (French-Indian collaboration) and NSF
- multi-agent optimization using tools from non-cooperative games within a research grant from FRANCE TELECOM R&D. In particular, we have studied pricing strategies in a competitive environment within this contract as well as within the ARCPRIXNET
- mathematical modeling of TCP supported by ARC TCP and by PAI POLONIUM and PAI VAN GOGH
- generation of synthetic multimedia traffic within the French RNRT project VTHD++ (Very High Broadband Network Service)
- singularly perturbed Markov chains and control of time-delay systems supported by PAI POLONIUM and PAI VAN GOGH
- analysis of service differentiation (in particular priority queueing) in cooperation with LYAPOUNOV INSTITUTE PROJECT
- performance evaluation of distribution content networks using stochastic fluid models
- analysis of processor-sharing scheduling disciplines, with the support of FRANCE TELECOM R&D.

3. 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.

4. Application Domains

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

- Internet: TCP, voice over IP, service differentiation, quality of service, multicast applications, content distribution systems, overlay networks, multimedia traffic generation
- Mobile networks: power control, medium access control, transmission rate control, redundancy in source coding, mobility models
- Satellite communications: IP over satellite links, planning and resource allocation.

5. Software

5.1. Allegro, a multimedia traffic generator

Keywords: *Audio and video traffic models*, *UDP traffic generator*.

Participants: Tania Jiménez, Philippe Nain, David Sagnol.

ALLEGRO is a multimedia traffic generator that is composed of three modules that can be used individually or altogether via a common graphical interface:

- a scenario builder that computes the instants of packet transmission and their size, according to a selected traffic model and predefined parameters (transmission rate, etc.)
- a UDP traffic generator that sends packets out in the network according to the pre-calculated scenario
- a monitoring tool providing statistical informations on the scenario execution.

The generation of audio traffic uses Markovian models (on-off models for unitary flows and MMPP-N models for aggregated flows). Video traffic is generated by using the so-called "M/G/∞ input process" for both unitary and aggregated flows. The goal is to generate UDP traffic that is representative of Internet traffic.

ALLEGRO supports the new version of the Internet Protocol (IPV6). It has been developed within the RNRT VTHD++ project (cf. section 7.3). In 2004 ALLEGRO was made publicly available at http://www-sop.inria.fr/maestro/soft/allegro.html

6. New Results

6.1. Quantitative analysis of protocols

Keywords: *DiffServ*, *FEC*, *LKH*, *RED*, *TCP*, *cross-layer analysis*.

Participants: Tigist Alemu, Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Urtzi Ayesta, Alain Jean-Marie, Tania Jiménez, Jussi Kyröhonka, Philippe Nain.

6.1.1. TCP protocol

Participants: Eitan Altman, Konstantin Avrachenkov, Urtzi Ayesta, Tania Jiménez.

6.1.1.1. RuN2C: A stateless architecture for differentiation of short and long TCP flows

Internet measurements show that a small number of long-lived TCP flows are responsible for the largest amount of data transferred, whereas most TCP sessions are made up of a few packets. Based on this fact, several recent studies have advocated the use of scheduling policies that would favor short jobs over long ones.

In collaboration with P. Brown (FRANCE TELECOM R&D) and E. Nyberg (Helsinki University of Technology, Finland), K. Avrachenkov and U. Ayesta propose in [34] a threshold based packet level scheduling

mechanism (RuN2C) that gives priority to the first part of every TCP connection. The scheme has the advantage of being stateless, TCP compatible and progressively deployable.

Simulation results as well as analytical study of a related two-level processor sharing model show that RuN2C has a very beneficial effect on the delay of short flows, while treating large flows as the current TCP implementation does. In contrast, LAS (Least Attained Service) scheduling policy can lead to pathological behavior in extreme cases.

The proposed network architecture for the differentiation of long and short TCP connections has been patented by FRANCE TELECOM R&D [59].

6.1.1.2. Cross-layer study for TCP over wireless network

The members of Maestro have a long tradition of studying and modeling the TCP protocol. In the continuation of this line of research, we have focused this year on the analysis of the impact of the physical layer, <the link layer and the network layer, on the performance of TCP.

In [29] E. Altman in collaboration with C. Barakat (INRIA project-team PLANETE) and V. Ramos-Ramos (UNSA) study the influence of the delay variation (which is typical to wireless networks which use retransmission on the link layer) on the TCP throughput. They derive explicit expressions for the throughput, in particular in the case where durations of successive round trip times are correlated.

In [35] E. Altman and D. Barman, in collaboration with I. Matta (Boston University, USA) and R. El Azouzi (University of Avignon, France), have analyzed and optimized the combined effects of power control, noisy links, forward error correction (adding redundant information which allows the reconstruction of some information lost due to noisy links or to congestion) and of local retransmissions of lost packets (ARQ) on the TCP throughput.

6.1.1.3. High-speed transport protocols

Due to the rapid increase of the bandwidth in networks (with links up to 10Gbps), the mechanisms of most of the existing versions of TCP that adapt to the available bandwidth turn out to be too slow, and need sometimes hours until they manage to grab the available bandwidth. Recently, new versions of TCP have been proposed which implement more aggressive mechanisms for adapting to the available throughput. We have studied the performance (throughout) of two such mechanisms among the mostly known ones, namely, High Speed TCP (proposed by S. Floyd) and Scalable TCP (proposed by T. Kelly).

E. Altman and R. El Khoury in [39] and E. Altman, K. Avrachenkov, A. Kherani and B. Prabhu, in collaboration with C. Barakat (INRIA project-team PLANETE) in [27] have used fluid models to calculate the throughput of Scalable TCP. The first paper addresses the case where losses are due to congestion: a TCP connection shares a bottleneck with some CBR traffic. The main finding is that Scalable TCP requires much less buffering than the mostly used TCP version (New Reno) in order to fully utilize the available bandwidth. In the second reference, considered is the situation where losses are due to a noisy link rather than or in addition to congestion. The analysis is based on an interesting relation to queueing theory: by taking the logarithm of the window size and/or the transmission rate, the resulting dynamics is described by a Lindley-like equation for the workload in a queue.

In [46] E. Altman, in collaboration with R. Márquez and S. Solé-Álvarez (both from the University of Los Andes, Venezuela), proposes an averaging method for analyzing the transient behavior of general TCP versions in the presence of a noisy channel. The method consists on transforming a "saw tooth" type behavior into smoothed dynamics described by differential equations with continuous right-hand side (this is the type of congestion control description introduced by F. Kelly). They have applied this method to both New Reno TCP and High Speed TCP, and have validated our analysis through ns simulations.

6.1.1.4. Session level analysis of TCP in overload

In [33] E. Altman and T. Jiménez, in collaboration with D. Kofman (ENST, Paris), study the expected file transfer duration where connections with different round trip times share a common bottleneck link. They consider overload conditions where the expected average rate of information is larger than the link's rate. They propose a DPS (Discriminatory Processor Sharing) queueing model which they solve under general stationary ergodic assumptions on the file sizes and arrival process, and validate the model by simulations with ns.

6.1.1.5. Performance analysis of DiffServ

In [20] E. Altman and C. Bakarat (INRIA project-team PLANETE) have studied the performance of TCP in differentiated services networks using a discretization approach along with a Markovian model. (This paper is the full journal version of a paper reported in a previous activity report.)

6.1.2. Improvements on RED (Random Early Detection)

Participants: Tigist Alemu, Alain Jean-Marie.

The congestion management mechanism RED (Random Early Detection) has been proposed more than ten years ago, and is recommended by the IETF. Yet, it is not deployed in the Internet. A reason for this is that setting properly its parameters is a difficult task. There is the need for a self-configuring RED mechanism. T. Alemu and A. Jean-Marie have proposed a new algorithm, named PSAND, which uses the information locally available at routers to adapt dynamically the rejection probability of RED. They have evaluated this mechanism through extensive simulations, and have shown that it is able to deliver a better quality of service than previously proposed Adaptive RED methods [25][12], [60]. They have compared PSAND with recently proposed and popular Active Queue Management algorithms (PI, BLUE, REM, AVQ, LRED) and have found that it offers an advantageous compromise, when evaluated over several metrics.

6.1.3. FEC (Forward Error Correction)

Participant: Alain Jean-Marie.

A. Jean-Marie and Y. Calas (IMAG, Grenoble, France) have investigated the use of Forward Error Correction (FEC) at the packet level in networks. They have proposed a new analysis of an audio coding scheme, recommended in the Internet in RFC 2198. The novelty of the analysis is that bursty traffic sources and cross-traffic are taken into account. Their general conclusion is that this FEC scheme does not significantly improve the audio quality (measured by an utility function), unless the traffic conditions are very bursty for the audio and the cross traffic [37], [65].

A. Jean-Marie and Y. Calas have also investigated the interaction of FEC and the queue management algorithms, specifically, RED (Random Early Detection) and the standard Drop Tail (DT) [58]. The starting point is that RED spreads randomly packet drops, so that it reduces consecutive losses. This property makes RED compatible *a priori* with the use of FEC at the packet level. They show, through simulations, that FEC combined with RED may indeed be more efficient than FEC combined with DT. This however depends on several parameters like the number of TCP flows that constitute the background traffic, the FEC block size and the amount of redundancy in a FEC block. They conclude that using FEC is in general more efficient with RED than with DT when the loss rate is small, and a relatively important amount of redundancy and at most a moderate FEC block size is used. On the other hand, the use of DT is more efficient for larger loss rates.

6.1.4. Secure multicast and anonymity systems

Participants: Sara Alouf, Alain Jean-Marie, Jussi Kyröhonka, Philippe Nain.

6.1.4.1. Secure multicast

In the context of secured multicast communications, it is crucial to have all members receive the data encryption key, as any member missing this key will be *de facto* excluded from the multicast group. Furthermore, to maintain the secrecy of the data, the data encryption key has to be changed every time a member joins/leaves. We are interested in a group rekeying protocol proposed by M. Önen and R. Molva (EURECOM INSTITUTE) which separates the members according to their membership duration. The idea is to preserve long-lived (permanent) members from the repeated key updates caused by volatile members. The protocol used for updating the keys is basically the Logical Key Hierarchy (LKH) protocol to which reliability mechanisms, such as Forward Error Correction (FEC), have been added. There are several pending issues in this protocol. The most important one concerns the duration of the testing period: after how much time is a member considered to be permanent? Another issue concerns the amount of FEC that is needed to ensure a maximum reliability.

To better address these issues, one has to estimate the number of members in the multicast group (see for instance [26]). In the context of a three-month summer internship, J. Kyröhonka (EURECOM INSTITUTE) has implemented a simulator, written in C language, that allows to compute the update cost under a wide variety of conditions. On-going research focus on modeling the system and evaluating the performance of the protocol at hand.

This work has been carried out in the context of the COLOR DISCLESURE (cf. Section 8.4.1).

6.1.4.2. Anonymity systems

Systems that allow users to communicate anonymously with a destination have received increasingly more attention since users of network applications became more concerned with their privacy. Unfortunately, anonymity systems are vulnerable to attacks that attempt to reveal the identity of nodes that communicate anonymously. Moreover, the distributed nature of such systems facilitates certain types of attacks. In [53], P. Nain, D. Figueiredo and D. Towsley (both from the University of Massachusetts, USA) focus on the so-called *predecessor attack*, a robust traffic analysis attack that targets nodes that communicate with the same destination repeatedly over time. Their results show that for a common class of protocols, where paths are constructed uniformly at random, the attack always succeeds and the effort required by the attackers is proportional to the number of initiators and the number of nodes in the system. Understanding the capabilities and limitations of this attack is an important step toward designing more secure anonymity systems.

6.2. Wireless networks

Keywords: *IEEE 802.11*, *MAC*, *UMTS*, *ad-hoc networks*, *multi-spot*, *satellites communications*, *slotted Aloha*.

Participants: Sara Alouf, Eitan Altman, Tania Jiménez, Robin Groenevelt, Arzad Kherani, Daniele Miorandi.

6.2.1. Cellular networks

Participants: Eitan Altman, Ioannis Koukoutsidis.

6.2.1.1. Control and optimization in UMTS networks

The UMTS (Universal Mobile Telecommunications System) is the standard of third generation cellular networks that is being deployed in Europe. We have been pursuing our work on resource allocation and optimization within a three years contract with FRANCE TELECOM R&D.

In [41] E. Altman and J.-M. Kelif (FRANCE TELECOM R&D) consider various objectives of quality of service: blocking probabilities, mean transfer duration of data transfers as well as the same mean but conditioned on the size of the file. The analysis allows them to design and to optimize call admission policies as well as rate control of the interactive calls.

In [55] E. Altman, I. Koukoutsidis and J.-M. Kelif address the situation where all data connections transmit simultaneously using CDMA (whereas in [41] only one data connection is allowed to transmit at a time). They show that the CDMA approach is less efficient than the time-division approach.

6.2.2. Wlan access

Participants: Sara Alouf, Eitan Altman, Tania Jiménez, Arzad Kherani, Daniele Miorandi.

6.2.2.1. TCP over WLAN

The study of TCP over multi-hop ad hoc network raises new challenges. In addition to drops due to congestion in queues, already encountered in wireline and wireless networks, and to noisy channels (already encountered in WLANs and in cellular wireless networks), there are now losses due to contention and to the limitation of the possibilities for spatial reuse. This type of drops has an important impact on reducing TCP throughput.

In [42] A. Kherani and R. Shorey (IBM Research Lab., New Delhi) study a way to reduce these drops which is to reduce the rate of TCP acknowledgments from the destination. They analyze the TCP performance with and without this mechanism and evaluate the achievable gain.

IEEE 802.11 represents the *de facto* standard for wireless local area networks. In this context, we were interested in modeling the performance of long and short-lived TCP flows in this kind of networks. In [45]

D. Miorandi, A. Kherani and E. Altman propose a simple equivalent saturation model for addressing the performance, in terms of average throughput, of competing TCP connections over an 802.11 WLAN. This result is then used to build an equivalent queueing model for the session level in the presence of short-lived flows.

6.2.2.2. Designing a new backoff algorithm in IEEE 802.11 MAC protocol

In collaboration with R. van der Mei (CWI and Vrije Universiteit, The Netherlands) S. Alouf has worked on the backoff algorithm used in the Medium Access Control (MAC) layer of the IEEE 802.11 standard. Given the number of contending terminals, it is possible to ideally set the contention window that will maximize the system throughput. Previous simulations with NShave shown that a substantial increase in the system overall throughput can be achieved, in particular for large numbers of active terminals. On-going work focus on modeling the behavior of the proposed backoff algorithm in order to derive an analytical expression relating the optimal contention window size to the current number of users.

6.2.3. Ad hoc and sensor networks

Participants: Eitan Altman, Daniele Miorandi, Robin Groenevelt, Ahmad Al Hanbali, Arzad Kherani, Philippe Nain.

6.2.3.1. Mobility models

A number of mobility models have been proposed for the purpose of either analyzing or simulating the movement of users in a mobile wireless network. Two of the more popular are the random waypoint and the random direction models. The random waypoint model is physically appealing but difficult to understand. Although the random direction model is less appealing physically, it is much easier to understand. User speeds are easily calculated, unlike for the waypoint model, and user positions and directions are uniformly distributed. In [56] P. Nain, in collaboration with D. Towsley (University of Massachusetts, USA), B. Liu (University of Massachusetts-Lowell) and Z. Liu (IBM TJ Watson Research Center, USA), has established this last property for a rich class of random direction models that allow future movements to depend on past movements.

6.2.3.2. Message delay in ad hoc networks

Ad hoc networks often experience disconnectivity when the node density is not high enough. A well-known solution proposed, and analyzed by Tse and Grossglauser, is to use nodes as relay nodes. A relay node carry along packets for other mobiles, and then transmit a packet when it is sufficiently close to the destination (or to another relay node). In the case where nodes moves according to independent Brownian motions on a one-dimensional segment, R. Groenevelt, E. Altman and P. Nain have investigated in [40] the performance of forwarding and relaying in terms of the average time that a packet takes to reach its destination (message delay) which is located several hops away from the source.

R. Groenevelt and P. Nain (in collaboration with G. Koole from the Vrije Universiteit of Amsterdam, The Netherlands) have introduced in [54] a generic stochastic model that accurately predicts the message delay in a mobile ad hoc network when nodes can relay messages. The model has only two input parameters: the number of nodes and the intensity of a finite number of homogeneous and independent Poisson processes modeling instances when any pair of nodes come within transmission range of one another. Explicit expressions are obtained for the Laplace-Stieltjes transform of the message delay, from which the expected message delay is derived in closed-form. These calculations are carried out for two relay protocols: the two-hop relay and the unrestricted relay protocols. Despite its simplicity, the model is able to accurately predict the performance of both relay protocols for a number of mobility models (Random Waypoint, Random Direction and Random Walker Mobility Models), as shown by simulations.

6.2.3.3. TCP over ad hoc networks

TCP was designed to provide reliable end-to-end delivery of data over unreliable networks. In practice, most TCP deployments have been carefully designed in the context of wired networks. Ignoring the specifics of wireless ad hoc networks can lead to TCP implementations with poor performance. In order to adapt TCP to

ad hoc environment, improvements have been proposed in the literature. In [48] A. Al Hanbali, E. Altman and P. Nain survey the main proposals which have been made to adapt TCP to static and mobile ad hoc networks.

When studying TCP over ad hoc networks, one has to model the interference due to contention between packets of neighboring nodes, which is considerably more complex than the wireless LAN case. In [43] A. Kherani, in collaboration with R. Shorey (IBM Research Lab., New Delhi), has investigated the performance of TCP over a multi-hop wireless LAN based on the IEEE 802.11 protocol with a small number of nodes. The fact that only a few nodes are considered allows us to avoid further complications arising from the exposed and the hidden terminal effects.

6.2.3.4. Coverage and connectivity

One important issue, in ad hoc wireless networks, is the characterization of the limiting performance, in terms of both connectivity and coverage. In [44] E. Altman and D. Miorandi use an infinite-server queueing model to study connectivity issues in one-dimensional ad hoc networks. The impact of various node placement statistics is analyzed and discussed. Broadcast percolation in the presence of fading and shadowing is studied, and it is shown how the flexibility of the proposed model may be used to investigate the performance enhancement achieved by means of diversity techniques.

Previous studies on the coverage of mobile sensor networks focus on algorithms to reposition sensors in order to achieve a static configuration with an enlarged covered area. In [68], P. Nain, B. Liu (University of Massachusetts-Lowell, USA), P. Brass, O. Dousse (both from EPFL, Switzerland), and D. Towsley (University of Massachusetts, USA) study the dynamic aspects of the coverage of a mobile sensor movement. As time goes by, a position is more likely to be covered; targets that might never be detected in a static sensor network can now be detected by moving sensors. They characterize the area coverage at specific time instants and during time intervals, as well as the time it takes to detect a randomly located static target. The results show that sensor mobility can be exploited to compensate for the lack of sensors and improve the network coverage. For mobile targets, they take a game theoretic approach and derive optimal mobility strategies for sensors and the targets from their own perspectives.

6.2.3.5. Equilibria and convergence of access attempt rates

In [32][36] E. Altman and A. Kherani (in cooperation with V. Borkar from Tata Institute of Fundamental Research, Mumbai, India, for the former work) consider the problem of optimizing transmission rates in a distributed wireless network. The problem was formulated as a multi-agent game problem. An algorithm for adaptively learning the Nash equilibrium of the game was proposed and analyzed, and was also tested on simple examples. Several variations of the basic scheme were proposed and analyzed.

6.2.4. Satellite communications

Participants: Sara Alouf, Eitan Altman.

Jointly with J. Galtier (FRANCE TELECOM R&D and INRIA project-team MASCOTTE), J.-F. Lalande (INRIA project-team MASCOTTE) and C. Touati from the University of Tsukuba, Japan, S. Alouf and E. Altman we have worked on documenting their previous study on multi-spot MFTDMA(Multi-Frequency Time-Division Multiple Access) geostationary satellite systems. They have proposed an algorithm that deals with planning a time/frequency plan for a set of terminals with a known geometric configuration under interference constraints. The objective was to maximize the system throughput while guaranteeing that the different types of demands are satisfied, each type using a different bandwidth. We have relied on two main techniques, the first generates admissible configurations for the interference constraints, whereas the second uses linear and integer programming with column generation. The obtained solution estimates a possible allocation plan with optimality guarantees, and highlights the frequency interferences which degrade the construction of good solutions. See [49], [62] and [61].

6.3. Content distribution networks and WWW

Keywords: *P2P network*, *Web cache*, *fluid model*, *prefetching*.

Participants: Konstantin Avrachenkov, Florence Clévenot, Philippe Nain.

6.3.1. WWW

Participants: Konstantin Avrachenkov, Philippe Nain.

6.3.1.1. Document ranking in WWW

Surfers on the Internet frequently use search engines to find pages satisfying their queries. However, there are typically hundreds or thousands of relevant pages available on the Web. Thus, listing them in a proper order is a crucial and non-trivial task. PageRank is one of the principle criteria according to which Google ranks Web pages. PageRank can be interpreted as a frequency of visiting a Web page by a random surfer and thus it reflects the popularity of a Web page. They provide the analysis of the Google PageRank from the perspective of the Markov chain theory.

In [51] K. Avrachenkov and N. Litvak (University of Twente) study the effect of newly created links on Google PageRank. They discuss to what extend a page can control its PageRank. Through an asymptotic analysis they provide simple conditions that show if new links bring benefits to a Web page and its neighbors in terms of PageRank or they do not. They conclude that a Web page benefits from links inside its Web community and on the other hand irrelevant links penalize the Web pages and their Web communities. In [50] K. Avrachenkov and N. Litvak study the Google PageRank for a Web that can be decomposed into several connected components which do not have any links to each other. They show that in order to determine the Google PageRank for a completely decomposable Web, it is sufficient to compute a subPageRank for each of the connected components separately. Furthermore, they demonstrate that there exists an optimal linking strategy.

6.3.1.2. Prefetching in the WWW

Network congestion remains one of the main barriers to the continuing success of the Internet. One possible remedy to the latency problem is to use caching at the client, at the proxy server, or even within the Internet. However, WWW documents are becoming increasingly dynamic (i.e., have short lifetimes), which limits the potential benefit of caching. The performance of a WWW caching system can be dramatically increased by integrating document prefetching into its design. While prefetching reduces the perceived user response time, it also increases network load, which in turn may increase the response time. In [64], A. Balamash, M. Krunz (both from the University of Arizona, USA) and P. Nain have investigated this tradeoff through a mathematical model of a WWW caching/prefetching system. From the analysis and/or the simulations, they observe that: (1) prefetching *all* documents whose access probabilities exceed a given threshold value may, surprisingly, degrade the delay performance, (2) the variability of WWW file sizes has a detrimental impact on the effectiveness of prefetching, and (3) coexistence between caching and prefetching is, in general, beneficial for the overall performance of the system, especially under heavy load.

6.3.2. Peer-to-peer systems

Participants: Florence Clévenot, Philippe Nain.

Peer-to-peer (P2P) systems exhibit two types of events: user connection/disconnection events, and requests for multimedia files or Web objects. In [38], [66], F. Clévenot and P. Nain propose simple mathematical models, where request streams are represented as fluid flows modulated by user arrivals/departures, and apply them to analyze the performance of Squirrel, a new P2P cooperative Web cache. These work differ from [52] by the same authors (together with K. W. Ross for Polytechnic University, New York) in the sense that clients and caches are now the same entities, so that the global request rate now depends on the active node population. The fluid model provides a low-complexity means to estimate the performance of Squirrel (hit probability, latency) and exhibits some key qualitative properties of this system. A comparison with discrete-event simulation validates the accuracy of the model. In addition, the generic analysis does not restrict to Squirrel but also applies to any P2P file sharing system based on distributed hash tables (such as CAN, Chord or Pastry for instance), provided documents are not replicated in the system.

6.4. Application of game theory to networking

Keywords: *Noncooperative games*, *pricing*.

Participants: Eitan Altman, Konstantin Avrachenkov, Tania Jiménez, Balakrishna Prabhu.

6.4.1. Priority level in a DiffServ environment

In [31] E. Altman, D. Barman (Boston University, USA), R. El Azouzi (University of Avignon, France), D. Ross and B. Tuffin (both from INRIA projet-team ARMOR), study the sharing of a multi-red buffer by TCP and UDP traffic. They consider as performance measures the throughput, the delays, and the loss probabilities. The relative quality of service of a connection depends on the priority assigned to it. They introduce payoffs for both TCP and UDP flows that are function of the performance measures as well as of the price for the chosen priority. They model the selection of the priority level as a non-cooperative game and study the properties of the equilibria. They thus study the optimal pricing of the priorities by the service provider so as to maximize its own benefits.

6.4.2. Determining access probabilities in ALOHA

In [18] E. Altman and T. Jiménez, in collaboration with R. El Azouzi (University of Avignon, France), address the problem of choosing in a non-cooperative way the transmission attempt probability of mobile users so as to maximize the individual goodput. They further compare their results to those obtained under a cooperative scenario. In the cooperative scenario, they find that at high loads the optimal goodput is achieved at the expense of huge delays of backlogged packets (i.e. packets which have collided). This finding motivated them to consider this delay as an alternative or as an additional objective of the mobiles. The latter gives rise to a game formulation in which each player (mobile) is faced with a multi-objective optimization problem. These models are studied in [30] by the same authors (along with D. Barman from Boston University, USA); they derive explicit expressions for the performance measures of interest, and study equilibrium issues.

6.4.3. Surveys of applications of game theory to networking

Models related to game theory applied to routing (or to the route assignment problem) have been developed in transportation long before they started to appear in the area of telecommunications. These two communities have had little interactions and often useful results obtained by one community were not known by the other. Moreover, related problems have been studied independently by researchers in the community of computer science and also by a community of mathematicians specialized in game theory. This situation has motivated E. Altman and L. Wynter (IBM TJ Watson Research Center, USA) to edit a special volume of the journal *Networks and Spatial Economics* on crossovers between the various disciplines and also to contribute to this volume [17]. In parallel, E. Altman, T. Boulogne (University of Paris VI), R. El Azouzi (University of Avignon, France), T. Jiménez and L. Wynter (IBM TJ Watson Research Center, USA) have written a much more general survey [15] of applications of game theory to telecommunications.

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

Keywords: *MDP*, *Markov chain (MC)*, *conjectural variations*, *perturbed MC*, *processor-sharing disciplines*, *stochastic scheduling*.

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

6.5.1. Advances in game theory

Participant: Alain Jean-Marie.

6.5.1.1. Theory of conjectural variations

Game-theoretic models are increasingly popular to model the competitive interaction of users of the Internet in various settings. Concepts elaborated in economics are applied to networking, which motivates a proper understanding of the rationality of economic agents. In addition to the classical Nash equilibrium, which models a purely non-cooperative behaviors, other behaviors are possible, which are intermediate between non-cooperative and cooperative (i.e. Pareto-optimal) behaviors. Among those, Alain Jean-Marie, C. Figuières

and M. Tidball (both from INRA Montpellier, France) have developed an analysis of Conjectural Variations Equilibria, which may be appropriate to describe agents faced with incomplete information on their opponent's preferences and reactions. They have studied several issues related to this concept, such as the qualitative comparison with Nash equilibria and Pareto outcomes [22], dynamic adaptation (learning) of conjectures [67], and have collected the results in a book [11].

6.5.2. Advances in control theory

Participant: Eitan Altman.

6.5.2.1. Discrete-event control of stochastic networks

E. Altman, B. Gaujal (INRIA project-team TRIO) and A. Hordijk (University of Leiden, The Netherlands) have developed a theory for the discrete-event control of stochastic networks. This work, based on the concept of multimodularity (which is the proper parallel of convexity over functions over the integers or over vectors of integers), has been published in various journals and conference proceedings (see previous activity reports of the project-team MISTRAL). All the results have been collected in a book [10] that appeared in December 2003.

6.5.2.2. Applications of constrained MDPs in marketing

In [21] E. Altman, in collaboration with W. K. Ching, M. K. Ng and K. K. Wong (all from the University of Hong Kong), uses the theory of constrained MDPs (Markov decision processes) to study and optimize marketing policies, under budget constraints, based on promotion strategies that are used to attract new and to keep current customers.

6.5.3. Advances in stochastic processes

Participants: Eitan Altman, Konstantin Avrachenkov.

6.5.3.1. Denumerable perturbed Markov chains

In [14] E. Altman and K. Avrachenkov together with R. Núñez Queija (CWI, The Netherlands) have analyzed the parametric perturbation of Markov chains with denumerable state spaces. Both regular and singular perturbations have been considered. By the latter it is meant that transition probabilities of a Markov chain, which has several ergodic classes, is perturbed in a way that allows rare transitions between the different ergodic classes of the unperturbed chain. In the previous work the singularly perturbed Markov chains were studied under restrictive assumptions such as strong recurrence ergodicity or Doeblin conditions. The goal is to relax these by conditions that can be applied to queueing models (where the conditions mentioned above typically fail to hold). With the help of the ν-geometric ergodicity approach, they are able to express explicitly the steady-state distribution of the perturbed Markov chain as a Taylor series in the perturbation parameter. The general results were then applied to quasi-birth and death processes and priority queues.

6.5.3.2. Application of singularly perturbed Markov chains to RED

Routers in the Internet use various policies to discard packets in order to to signal onset of congestion. One such policy, the Random Early Discard (RED) policy, drops packet based on an estimate of the average queue-length. In [28], E. Altman, K. Avrachenkov and B. Prabhu analyze an M/M/1 queue where the packet drop probability depends on the average queue-length estimate. With the help of singularly perturbed Markov chains, they derive the joint distribution of the average queue-length and the instantaneous queue-length, along with packet drop probability when the averaging parameter goes to 0. For the non-limiting case they use a known "quasi-birth death" (QBD) algorithm to calculate the stationary joint queue-length distribution.

6.5.3.3. Singularly perturbed Markov chains with transient states

There are a few procedures for computing the Laurent series expansions for the mean passage time matrix and for the deviation matrix of a singularly perturbed Markov chain. In [19] K. Avrachenkov and M. Haviv (Hebrew University, Jerusalem, Israel) propose a method for computing the most significant singular matrices in these expansions in a way which highlights the system dynamics in various time-scales.

6.5.4. Advances in queueing theory

Participants: Kostantin Avrachenkov, Urtzi Ayesta.

6.5.4.1. Batch arrival processor sharing

In collaboration with P. Brown (FRANCE TELECOM R&D), K. Avrachenkov and U. Ayesta analyze in [63] a Processor-Sharing (PS) queue with batch arrivals. The analysis is based on the integral equation derived by Kleinrock, Muntz and Rodemich. Using the contraction mapping principle, they demonstrate the existence and uniqueness of a solution to the integral equation. Then, they provide an asymptotic analysis as well as tight bounds for the expected response time conditioned on the service requirement. In particular, asymptotics for large service requirements are shown to depends only on the first-order moment of the service requirements distribution and on the first and second-order moments of the batch size distribution. That is, similarly to the PS queue with single arrivals, in the PS queue with batch arrivals the expected conditional response time is finite even when the service time distribution has an infinite second-order moment. Finally, they show how these results can be applied to the analysis of Multi-Level Processor Sharing scheduling disciplines.

6.5.4.2. Multi-Level Processor-Sharing Scheduling Disciplines

In collaboration with S.Aalto and E.Nyberg (both from Helsinki University of Technology, Finland), U. Ayesta presents in [24] a mean delay analysis of the Multi-Level Processor Sharing (MLPS) scheduling disciplines. Under MLPS, jobs are classified into classes depending on their attained service. They consider MLPS scheduling disciplines where jobs within the same class are served either with Processor-Sharing (PS) or Foreground Background (FB) policy. The class that contains jobs with the smallest attained service is served first. It is known that the FB policy minimizes (maximizes) the mean delay when the hazard rate of the job size distribution is decreasing (increasing). The analysis, based on pathwise and meanwise arguments of the unfinished truncated work, shows that Two-Level Processor Sharing (TLPS) disciplines, e.g., FB+PS and PS+PS, are better than PS scheduling when the hazard rate of the job size distribution is decreasing. If the hazard rate is increasing and bounded, it is shown that PS outperforms PS+PS and FB+PS. The analysis is further extended to study local optimality within a level of an MLPS scheduling discipline.

In addition, in [47] the same authors have shown that any MLPS discipline is better than the PS discipline with respect to the mean delay whenever the hazard rate of the service time distribution is decreasing.

6.5.4.3. Application of games to queueing theory

In [16], E. Altman and T. Jimenez, in collaboration with and R. Núñez Queija (CWI, The Netherlands) and U. Yechiali (University of Tel Aviv, Israel), consider individual jobs that have to decide whether to get served at a queue whose occupancy they observe or to get served at a downstream unobservable queue instead. Each job tries to minimize its own expected sojourn time. They compute the performance of threshold type policies in which when a job finds less than l customers at the observable queue then it goes to that queue, if there are more than l then he goes to the other one, and it decides at random where to go when it finds exactly l jobs waiting in the observable queue. They identify conditions under which an equilibrium exists within such policies. In contrast, they identify cases where no threshold policy is optimal for an individual given that all other jobs use a threshold policy.

7. Contracts and Grants with Industry

7.1. Collaboration with France Telecom R&D on Umts

Participants: Eitan Altman, Konstantin Avrachenkov, Ioannis Koukoutsidis, Balakrishna Prabhu.

We have pursued the second year of our collaboration with FRANCE TELECOM R&D at Issy-les-Moulineaux on developing strategies for resource allocation and optimization in UMTS. In 2004 we have investigated the capacity of UMTS networks in the presence of both real-time as well as elastic traffic. This collaboration has given rise to a patent on optimal and fair bandwidth allocation and call admission control in UMTS.

A new two-year collaboration (Contrat de Recherche Externalisée – CRE) with FRANCE TELECOM R&D at Issy-les-Moulineaux devoted to the "Optimization and Control of UMTS and WLANs" will start on January

2005. E. Altman will be the coordinator for INRIA and J.-M. Kélif will be the coordinator for FRANCE TELECOM R&D.

7.2. Collaboration with France Telecom R&D on Internet traffic

A new two-year collaboration (Contrat de Recherche Externalisée – CRE) with FRANCE TELECOM R&D at Sophia Antipolis on the "Modeling and Optimization of Internet Traffic" will start on January 2005. P. Nain will be the coordinator for INRIA and P. Brown will be the coordinator for FRANCE TELECOM R&D.

7.3. Rnrt Vthd++

Participants: Tania Jiménez, Philippe Nain, David Sagnol.

In this project (ended on December 2004) MAESTRO was in charge of developing and deploying ALLEGRO, a multimedia traffic generator (see Section 5.1) that creates on demand a realistic background traffic on the VTHD platform.

The VTHD++ project was the successor of the VTHD project, in which MISTRAL (the predecessor of MAESTRO) deployed WAGON, a Web traffic generator, on the VTHD platform (see 2000-2003 MISTRAL activity reports).

Both softwares ALLEGRO and WAGON ran on a hundred dedicated workstations connected to the VTHD platform, deployed at 8 different geographical sites. Several test campaigns qualitatively and quantitatively assessed the performance of these traffic generators. Monitoring tools (Cricket, Smokeping) were installed at INRIA in Rocquencourt and in Sophia Antipolis.

ALLEGRO is publicly available at http://www-sop.inria.fr/maestro/soft/allegro.html

8. Other Grants and Activities

8.1. International initiatives

8.1.1. Network of Excellence: Euro-Ngi

MAESTRO is a member of the Network of Excellence (NoE) EURO-NGI on "Design and Engineering of the Next Generation Internet, Towards Convergent Multi-Service Networks". E. Altman is the co-coordinator of the work package on "Control and Optimization in Telecommunication Networks". We have organized within this work package a workshop at INRIA with the participation of around 50 persons (October 14-15, 2004).

8.1.2. Collaboration with India: Cefipra

Since April 2003 MAESTRO has been involved in a three-year research grant with Prof. A. Kumar and Prof A. Chockalingam, both from IISc (Bangalore), and with Prof V. S. Borkar from Tata Institute of Fundamental Research (Mumbai). The coordinators of this project are Prof. A. Kumar and E. Altman for the Indian and French institutions, respectively. The theme of the cooperation is "New Strategies for Wireless Communication Networks." This cooperation finances the two-year postdoctoral position at INRIA of A. A. Kherani. We had visits of Prof. A. Kumar and Prof. Chockalingam to our group, and visits of B. Prabhu, A. A. Kherani and E. Altman to INDIA.

8.1.3. Collaboration with the Netherlands: Pai Van Gogh

MAESTRO, together with three Dutch teams: a team from CWI (S. Borst, M. Mandjes, R. Núñez Queija,), a team from Eindhoven University (O. J. Boxma, J. Resing, B. Zwart), and a team from University of Twente (N. Litvak, W. Scheinhardt) participates in the PAI VAN GOGH on the "Mathematical Analysis of TCP/IP Protocols and the Web Structure". This project started in 2003 and has been extended for 2004.

8.1.4. Collaboration with Venezuela

In January 2004 we started a four-year collaboration with the University of Los Andes (ULA), Merida, Venezuela, funded by the ECOS program. On the French side the project involves D. Ros (ENST Bretagne), I.

Attali and D. Caromel (INRIA project-team OASIS), H. Mounier (University of Paris Sud XI) and E. Altman (coordinator of the French side). Our Venezuelian partners are R. Márquez, T. Jiménez, L. Leon and J. Aguilar from ULA (Merida). Within this project we have hosted this year R. Márquez and L. Leon at INRIA (both for three weeks), and E. Altman visited ULA for two weeks.

8.1.5. Collaboration with Poland: Pai Polonium

MAESTRO, together with INRIA project-teams METALAU (J.-P. Quadrat) and SOSSO (P.-A. Bliman), is involved in a PAI Polonium in parternship with a team from the University of Zielona Gora (K. Galkowski, W. Paszke, and B. Sulikowski). The collaboration bears on the "Analysis of Time Delay Systems, Repetitive Control and Its Application to Telecommunication Systems".

8.1.6. Collaboration with the USA: Nsf Itr

Members of MAESTRO and the University of Massachusetts (UMass) at Amherst (Prof. D. Towsley) have a long lasting collaboration in the area of performance evaluation and control of networks. Since 2001, we have been associated with UMass in a five-year NSF ITR project on "QoS in the future Internet". This project finances visits of members of MAESTRO to UMass. In 2004 P. Nain visited UMass in this framework.

8.2. National initiative

8.2.1. Incitative coordinated actions (ACI)

Members of MAESTRO are involved in several ACI (Incitative Coordinated Actions) sponsored by the CNRS, INRIA, the Ministry of Education and Research and other institutions. One is the the FLUX project of the ACI "Masses of Data". Its main topic is the use of probabilistic counting to devise lightweight algorithms for flow classification in networks. The second one is the SR2I (Security of Interdomain Routing in the Internet) of the ACI "Security in Informatics", the topic of which is the reliability and security of the BGP routing protocol.

8.2.2. Specific actions (AS)

MAESTRO is involved in a research initiative (Actions Spécifiques - AS) of CNRS, on "Random Models and the Performance of Distributed Systems" (AS 182)[1].

8.3. INRIA new investigation grant

8.3.1. Arc Prixnet

MAESTRO is a member of ARC PRIXNET[2] which aims at developing, implementing and comparing new pricing schemes for telecommunication networks. Our partners are: INRIA project-team ARMOR, FRANCE TELECOM R&D, PRiSM Lab. (University Versailles) and IBM T.J. Watson Research Center, USA. We have had a workshop in Paris on November 4-5, 2004.

8.3.2. Arc Tcp

Since February 2002 MAESTRO has been the coordinating team of the Cooperative Research Initiatives (ARC in French) "Models and Algorithms for TCP/IP Networks".[3] The initial duration of this ARC was two years but a third year has been granted to this project. The project ended at the end of 2004. This ARC was composed of six INRIA project-teams (ARMOR, HIPERCOM, MAESTRO, PLANETE, TREC, RAP), one team from LIRMM, a CNRS/University Montpellier research laboratory, three teams from FRANCE TELECOM R&D (Issy-les-Moulineaux, Lannion and Sophia Antipolis) and one team from EPFL.

ARC TCP had two main goals: to keep all participating teams informed of on-going research in this active area of TCP/IP modeling, and to enable new collaborations among participating members. ARC TCP budget supports short-term visits of researchers and students of participating teams as well as visits

[1] http://www.lirmm.fr/~ajm/AS182/
[2] http://www.irisa.fr/armor/Armor-Ext/RA/prixnet/ARC.htm
[3] http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/ARC_TCP.html

from researchers and interns from outside the group. The third ARC TCP Workshop took place on October 12-13, 2004 at INRIA-Sophia[4] and gathered over 50 participants. In addition to ARC TCP members, the following distinguished researchers have given lectures during this workshop: T. Ott (New Jersey Institute of Technology), M. Sidi (Technion), S. Mascolo (Politecnico di Bari).

8.4. Regional collaborations

8.4.1. Action Color DisCleSure with Eurecom Institute (Sophia Antipolis)

Participants: Sara Alouf, Alain Jean-Marie, Jussi Kyröhonka, Philippe Nain.

Since April 2004 MAESTRO has been the coordinating team of a Regional Research Cooperation (COLOR in French) with EURECOM INSTITUTE (R. Molva, M. Önen). The research theme is the reliability of keys distribution protocols - see section 6.1.4.

8.5. Visiting scientists

8.5.1. Europe

K. Galkowski (I.C.C.E. University of Gora, Poland, 11/18/04–11/24/04), G. Koole (Vrije University of Amsterdam, Netherlands, 04/26/04–05/07/04), B. Miller (Russian Academy of Sciences, Moscow, Russia, 11/20/03–01/31/04 and06/01/04–06/04/04), R. Núñez Queija (CWI, Amsterdam, Netherlands, 01/14/04–01/17/04 and 08/26/04–08/29/04), E. Nyberg (Helsinki University of Technology, Finland, 02/15/04–02/29/04), W. Scheinhardt (University of Twente, Netherlands, 05/06/04–05/11/04), N. Litvak (University of Twente, Netherlands, 06/18/04–06/25/04, 10/18/04–10/22/04), S. Mascolo (Politecnico di Bari, Italy, 09/25/04–10/30/04), D. Miorandi (University of Padova, Italy, 10/11/04–10/24/04).

8.5.2. America

T. Başar (University of Illinois, USA, 03/13/04–03/23/04), D. Towsley (University of Massachusetts, USA, 04/13/04–04/18/04), R. Márquez (University of Los Andres, Mérida, Venezuela, 10/30/04–11/30/04). J. Sun (MIT, Boston, USA, 10/16/04–11/1/04).

8.5.3. Maghreb and Middle-East

U. Yechiali (University of Tel Aviv, Israel, 04/07/04–04/16/04 and 09/01/04–12/31/04).

8.5.4. Asia

A. Chockalingam (IISc, Bangalore, India, 06/07/04–06/21/04)

8.5.5. Oceania

H. Sirisena (University of Canterbury, New Zealand, 06/23/04–06/26/04).

8.6. Visits of Maestro staff to other research institutions

S. Alouf visited the Vrije Universiteit in Amsterdam, on July 9 2004.

E. Altman visited the Indian Institute of Science (IISc) in Bangalore, India (November 21-December 12), the University of Los Andes (ULA), Merida, Venezuela (December 16 2004-January 5 2005), the University of Montreal, Canada (July 9-15), the University of Avigon, France (February 25-28), and the University of Montpellier, France (February 28-29). .

K. Avrachenkov visited the CWI and the University of Twente, The Netherlands (April 17-25), the University of St Petersbourg, Russia (January 15-30), andthe University of Bordeaux, France (March 24-28).

U. Ayesta visited the CWI in Amsterdam (March 15-19, 2004).

[4] http://www-sop.inria.fr/maestro/personnel/K.Avrachenkov/WebPage/Workshop3/index.html

A. Kherani visited the Indian Institute of Science in Bangalore (August 12), the Tata Institute of Fundamental Research in Mumbai (August 17), the IBM India Research Lab. in Delhi (August 30), the Indian Institute of Technology in Mumbai (August 31–September 1), and the University of Avignon (July 15-17).

P. Nain visited the University of Arizona at Tucson, USA, for two weeks in March 2004 and the University of Massachussetts, USA, for one week in June 2004.

B. Prabhu visited twice the CWI in Amsterdam (May 31–June 4 and November 10–December 10) and the Tata Institute of Fundamental Research (TIFR), Mumbai, India, for two weeks (August 9-22, 2004).

9. Dissemination

9.1. Leadership within the scientific community

9.1.1. Editorial activities

E. Altman is an Associate Editor of the following journals: *Journal of Economics, Dynamics and Control* (JEDC), *Stochastic Models*, *ACM/Kluwer Wireless Networks* (WINET), *Communication Networks* (COMNET) and *SIAM Journal on Control and Optimization* (SICON). He is a Guest Co-Editor (with R. Mazumdar and P. Nain) of a Special Issue of *Performance Evaluation* on Selected Papers from the First Workshop on Modeling and Optimization in Mobile Ad Hoc and Wireless Networks (WiOpt'2003) [57].

P. Nain is an Associate Editor of *Performance Evaluation* and *Operations Research Letters*. He is a Guest Co-Editor (with E. Altman and R. Mazumdar) of a Special Issue of *Performance Evaluation* on Selected Papers from the First Workshop on Modeling and Optimization in Mobile Ad Hoc and Wireless Networks (WiOpt'2003) [57].

9.1.2. Participation in technical program committees

E. Altman was a program committee member of the following conferences and workshops: IEEE INFOCOM 2004, March 7-11 2004, Hong Kong, Networking (IFIP working groups WG 6.2, WG 6.3, and WG 6.8), May 9-14, 2004, Athens, Greece, HET-NETs'04, July 26-28, 2004, Ilkley, UK, 3rd Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net 2004) Bodrum, Turkey, June 27-30, 2004, WONS 2004, the 1st Working Conference on Wireless On-demand Network Systems Madonna di Campiglio (Trento, Italy) January 21-23, 2004, EW2004, the 5th European Wireless Conference Mobile and Wireless Systems beyond 3G, February 24 - 27, 2004, Barcelona, Spain, the 1st IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS), October 25-27, 2004, Fort Lauderdale, FL, USA, 15th Specialist Seminar on "Performance Evaluation of Wireless and Mobile Systems", August 31 - September 02, 2004, Antwerp, Belgium, 12th IEEE International Workshop on Quality of Service (IWQoS 2004) June 7-9, 2004 Montreal, Canada, 4th Workshop on APplications and Services in Wireless Networks, August 9-11, 2004, Boston, MA, USA, and IEEE International Conference on Communications (ICC), June 20-24, 2004, Paris.

K. Avrachenkov was a program committee member of the following conferences: the IEEE International Conference on Networks (ICON 2004; Singapore, November 16 - 19, 2004) and Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt'04; University of Cambridge, UK, March 24-26, 2004).

P. Nain was a program committee member of the following conferences: IEEE INFOCOM 2004 (March 7-11 2004, Hong Kong), ACM SIGMETRICS (June 12-16, New York, USA), Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt'04, University of Cambridge, UK, March 24-26, 2004)

9.1.3. Conferences, meetings and tutorial organization

- E. Altman, K. Avrachenkov, P. Nain and E. Deriche organized the Third ARC TCP Workshop (October 12-13, 2004, INRIA Sophia Antipolis)
- E. Altman, K. Avrachenkov and E. Deriche organized a workshop of the EuroNgi Network of Excellence on "Network Optimization and Control" (October 14-15, 2004, INRIA Sophia Antipolis).

9.1.4. Participation to thesis committees

K. Avrachenkov participated in the PhD thesis committee of U. Ayesta (December 10, 2004).

E. Altman participated in the PhD thesis committees of Victor Ramos-Ramos (December 8, 2004, UNSA), Pietro Michiardi (December 14, UNSA), Thomas Boulogne (December 15, 2004, University of Paris VI), and G.-J. Franx (March 16, 2004, Vrije Universiteit, Amsterdam).

A. Jean-Marie participated in the PhD thesis committees of Fabien Mathieu December 8, 2004, University of Montpellier II), Tigist Alemu (13 December 2004, University of Montpellier II), and in the "Habilitation" thesis committee (Habilitation à Diriger des Recherches (HDR)) of Laurent Truffet (December 10, 2004, University of Nantes) and YeQiong Song (December 15, 2004, University of Nancy I, as a reviewer).

P. Nain participated as a reviewer in the HDR thesis committee of Jean-Marie Garcia (April 22, 2004, University of Paul Sabatier, Toulouse) and in the PhD thesis committees of Idris Rai (September 15, 2004, UNSA), Nadia Ben Azzouna (September 17, 2004, University of Paris VI), and Jean-Philippe Gayon (November 22, 2004, Ecole Centrale Paris). He participated as an examinator in the PhD thesis committees of Urtzi Ayesta (December 10, 2004, UNSA) and Tigist Alemu (December 13, 2004, University of Montpellier II).

9.1.5. Research administration

- **A. Jean-Marie**
  - is the Head of the APR (Algorithms and Performance of Networks) Project of the LIRMM Laboratory of the University of Montpellier II.
  - coordinates the curriculum of the Master Program in Computer Science, specialization in Research, at the University of Montpellier II.
  - is member of the Specialists Committee (Commission de Spécialistes) in Computer Science at the University of Montpellier II (as vice-president until October 2004)
  - acted as expert for the Scientific Council of IMAG (Institut d'Informatique et de Mathématiques Appliquées de Grenoble).
- **P. Nain**
  - is a member of the Scientific Council of the CNRT (Centre Nationaux de Recherche Technologiques) Telius (Telecom, Internet and Usage).
  - is a member of the Specialists Committee in Computer Science at the University of Nice Sophia Antipolis.
  - is in charge of the Master Program on "Networking and Distributed Systems" (Master RSD) at UNSA
  - is a member of the Board of the Project Committee of INRIA at Sophia Antipolis.

9.1.6. Miscellaneous

- **E. Altman**, **A. Jean-Marie** and **P. Nain** are (elected) members of IFIP WG 7.3 [5] on "Computer System Modelling". P. Nain is the treasurer of this working group (his term as a treasurer has been renewned for three more years in December 2004).

9.1.7. PhD thesis

The following PhD thesis were defended in 2004:

T. Alemu on December 13, 2004 [12]

U. Ayesta on December 10, 2004 [13].

9.2. Teaching

A. Jean-Marie participated to the course on "Dynamics and Algorithmics of Networks" of the Master in Computer Science MPRI (Paris 6/ENS/École Polytechnique, 12H), to the course on "Control of Telecommunication Networks" (DEA IRO, University of Paris VI, 12H). He taught courses on the Quality of Service in Networks in the Master Pro of the University of Montpellier II (30H).

P. Nain taught a course on Performance Evaluation of Computer Systems and Networks in the DEA RSD (Networks and Distributed Systems) at the University of Nice Sophia Antipolis (24H) and a course on "Control of Telecommunication Networks" (DEA IRO, University of Paris VI, 12H).

9.3. Conference and workshop committees, invited conferences

E. Altman was an invited speaker at the conference on "Stochastic Networks", Montreal, Canada, July 2004. He gave several lectures at the IEEE INFOCOM 2004 conference (March 7-11, 2004, Hong Kong) and at the Network Optimization and Control workshop of the EuroNgi Network of Excellence (October 14-15, 2004, Sophia Antipolis).

S. Alouf gave a presentation at the 16th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2004, July 5-9, 2004, Leuven, Belgium).

K. Avrachenkov gave a lecture at the Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN'04, February 2-6, 2004, St.Petersburg, Russia), at the International Conference on Informatics in Control, Automation and Robotics (ICINCO'04, August 25-28, 2004, Setubal, Portugal) and at the 16th ITC Specialist Seminar on Performance Evaluation of Wireless and Mobile Systems (August 31 - September 02, 2004, Antwerp, Belgium).

U. Ayesta gave a presentation at the IEEE INFOCOM 2004 conference (March 7-11 2004, Hong Kong), at the ACM SIGMETRICS 2004/Performance 2004 conference (June 12-16, 2004, New York), and at the Network Optimization and Control workshop of the EuroNgi Network of Excellence (October 14-15, 2004, Sophia Antipolis).

N. Bonneau gave a lecture at the Network Optimization and Control workshop of the EuroNgi Network of Excellence (October 14-15, 2004, Sophia Antipolis).

F. Clévenot presented a paper at the IEEE INFOCOM 2004 conference (March 7-11, 2004, Hong Kong).

R. Groenevelt presented a paper at the workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt'04), held at the University of Cambridge, UK, in March 2004.

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A. Jean-Marie gave three presentations at the department of Electrical Engineering of the University Federico Santa María, Valparaiso, Chile, and was invited to the Seminar in Performance Evaluation of Grenoble.

A. Kherani gave lectures at the Network Optimization and Control workshop of the EuroNgi Network of Excellence (October 14-15, 2004, Sophia Antipolis).

I. Koukoutsidis presented a paper at the 9th IFIP International Conference on Personal Wireless Communications (PWC 2004, September 21-23, 2004, Delft, The Netherlands).

P. Nain gave a lecture at the University of Arizona in Tuscon, USA.

B. Prabhu presented a paper at the IEEE International Conference on High Speed Networks and Multimedia Communications (HSNMC'04, June 30-July 2,2004, Toulouse, France) and at the International Working Conference on Performance Modelling and Evaluation of Heterogeneous Networks (HET-NETs'04, July 26-28, 2004, Ilkley, UK).

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