

*Project-Team mistral**Modeling of Computer Systems and
Telecommunication Networks: Research
and Software Development**Sophia Antipolis*

THEME 1B

The logo consists of a large, stylized, light blue 'A' on the left and a large, stylized, light blue 'R' on the right. The word 'Activity' is written in a light blue, sans-serif font across the top of the 'A'. The word 'Report' is written in a light blue, sans-serif font across the top of the 'R'. A horizontal line is drawn across the middle of the 'A' and 'R'.

2003

Table of contents

| | |
|---|-----------|
| 1. Team | 1 |
| 2. Overall Objectives | 2 |
| 3. Scientific Foundations | 2 |
| 4. Application Domains | 3 |
| 5. Software | 3 |
| 5.1. Allegro, a multimedia traffic generator | 3 |
| 6. New Results | 4 |
| 6.1. Quantitative analysis of protocols | 4 |
| 6.1.1. Tcp protocol | 4 |
| 6.1.1.1. Multi-level analysis of Tcp traffic | 4 |
| 6.1.1.2. Differentiation between short and long-lived Tcp sessions | 4 |
| 6.1.1.3. Tcp enhancements | 4 |
| 6.1.1.4. Red (Random Early Drop) | 5 |
| 6.1.2. Fec (Forward Error Correction) | 5 |
| 6.1.3. Early and selective discarding | 5 |
| 6.2. Wireless networks | 5 |
| 6.2.1. Cellular networks | 5 |
| 6.2.2. Wlan access | 6 |
| 6.2.3. Ad hoc networks | 6 |
| 6.2.3.1. Static ad hoc networks | 6 |
| 6.2.3.2. Relaying in mobile ad hoc network | 6 |
| 6.2.4. Satellite communications | 6 |
| 6.2.5. Threshold based channel switching policy for Tcp over Umts | 7 |
| 6.3. Content distribution networks | 7 |
| 6.3.1. Peer-to-peer systems | 7 |
| 6.4. Game theory applied to networking | 7 |
| 6.4.1. Noncooperative games in networks | 8 |
| 6.4.2. Cooperative games in networks | 8 |
| 6.5. Stochastic processes, queueing, control theory and game theory | 8 |
| 6.5.1. S-modular games and power control | 8 |
| 6.5.2. Priority queues and perturbed Markov chain | 9 |
| 6.5.2.1. Priority queueing with randomized push-out | 9 |
| 6.5.2.2. Singularly perturbed Markov chains with transient states | 9 |
| 6.5.3. Stability of queues | 9 |
| 6.5.3.1. Stability analysis of a Red-like queue | 9 |
| 7. Contracts and Grants with Industry | 9 |
| 7.1. Collaboration with Alcatel Space | 9 |
| 7.2. Collaboration with France Telecom R&D on game theory | 10 |
| 7.3. Collaboration with France Telecom R&D on Umts | 10 |
| 7.4. Rnrt Vthd++ | 10 |
| 8. Other Grants and Activities | 10 |
| 8.1. International initiatives | 10 |
| 8.1.1. Network of Excellence: Euro-Ngi | 10 |
| 8.1.2. Collaboration with India: Cefipra | 10 |
| 8.1.3. Collaboration with the Netherlands: Pai Van Gogh | 11 |
| 8.1.4. Collaboration with Poland: Pai Polonium | 11 |
| 8.1.5. Collaboration with Russia: Lyapounov Institute Projet | 11 |

| | | |
|------------|---|-----------|
| 8.1.6. | Collaboration with the USA: Nsf Itr | 11 |
| 8.2. | National initiative | 11 |
| 8.3. | INRIA new investigation grant | 11 |
| 8.3.1. | Arc Prixnet | 11 |
| 8.3.2. | Arc Tcp | 11 |
| 8.4. | Visiting scientists | 12 |
| 8.4.1. | Europe | 12 |
| 8.4.2. | America | 12 |
| 8.4.3. | Maghreb and Middle-East | 12 |
| 8.4.4. | Asia | 12 |
| 8.4.5. | Oceania | 12 |
| 8.5. | Visits of Mistral staff to other research institutions | 12 |
| 9. | Dissemination | 13 |
| 9.1. | Leadership within the scientific community | 13 |
| 9.1.1. | Editorial activities | 13 |
| 9.1.2. | Participation in technical program committees | 13 |
| 9.1.3. | Conferences, meetings and tutorial organization | 13 |
| 9.1.4. | Participation to thesis committees | 13 |
| 9.1.5. | Research administration | 14 |
| 9.1.6. | Miscellaneous | 14 |
| 9.1.7. | Ph.D. thesis | 14 |
| 9.2. | Teaching | 14 |
| 9.3. | Conference and workshop committees, invited conferences | 15 |
| 10. | Bibliography | 15 |

1. Team

Head of Mistral

Philippe Nain [DR]

Vice-head of Mistral

Eitan Altman [DR]

Administrative assistant

Ephie Deriche [TR, part-time, jointly with MASCOTTE]

Staff members (Inria)

Konstantin Avrachenkov [CR]

Alain Jean-Marie [DR, since 10/1/03]

Technical staff

Rachid El-Azouzi [FRANCE TELECOM R&D grant, until 09/30/03]

David Sagnol [RNRT VTHD grant, since 06/01/03]

Junior technical staff

Maria Ladoue [INRIA, until 08/21/03]

Post-doctoral fellows

Arzad Kherani [CEFIPRA fellowship, since 08/01/03]

Nidhi Hegde [RNRT VTHD grant, until 04/30/03]

Ph.D. students

Ahmad Al-Hanbali [MENRT fellowship, 1st year, since 10/01/03]

Urtzi Ayesta [FRANCE TELECOM R&D fellowship, 2nd year]

Florence Clévenot [MENRT fellowship, 2nd year]

Robin Groenevelt [RNRT VTHD fellowship, 3rd year]

Naceur Malouch [Lecturer UNSA¹, 4th year, until 09/30/03]

Daniele Miorandi [University of Padova fellowship, since 06/01/03, 3rd year]

Balakrishna Prabhu [INRIA/INTER fellowship, 2nd year]

Corinne Touati [MENRT fellowship, 3rd year until 09/01/03, jointly with MASCOTTE]

Visiting scientists

Tamer Başar [University of Illinois, USA, 03/18/03–03/31/03]

Geert-Jan Franx [Vrije University of Amsterdam, Netherlands, 12/12/02–01/02/03]

Krzysztof Galkowski [University of Zielona Gora, Poland, 09/12/03–09/22/03]

Moche Haviv [University of Sidney, Australia, 02/10/03–02/15/03]

Shivkumar Kalyanaraman [(Rensselaer Polytechnic Institute, Troy, USA, 03/12/03–03/17/03]

Hisao Kameda [University of Tsukuba, Japan, 07/18/03–08/06/03]

Ger Koole [Vrije University of Amsterdam, Netherlands, 04/28/03–05/09/03]

Marwan Krunz [University of Arizona, Tucson, USA, 04/15/03–08/05/03]

Anurag Kumar [IISc, Bangalor, India, 10/06/03–12/01/03]

Harold Kushner [Brown University Providence, USA, 04/05/03–05/04/03]

Jie Li [University of Tsukuba, Japan, 03/02/03–03/17/03]

Christoph Lindemann [University of Dortmund, Germany, 10/18/03–10/21/03]

Zhen Liu [IBM, New York, USA, 07/21/03–07/25/03]

Richard Marquez-Contreras [Univ. Los Andes, Mérida, Venezuela, 08/01/03–10/08/03]

Boris Miller [Russian Academy of Sciences, Moscow, Russia, 11/20/03–01/31/04]

Eeva Nyberg [Helsinki University of Technology, Finland, 01/20/03–01/26/03]

Rudesindo Nunez-Queija [CWI, Amsterdam, Netherlands, 03/10/03–03/14/03]

¹University of Nice Sophia Antipolis

Daniel Figueiredo [Univ. of Massachusetts, Amherst, USA, 10/27/03–10/31/03]
 Catherine Rosenberg [University of Purdue, USA, 06/02/03–06/03/03]
 Georgy Shevlyakov [St. Petersburg State University, Russia, 04/12/03–04/19/03]
 Uri Yechiali [University of Tel Aviv, Israël, 04/07/03–04/14/03]

Graduate students (intern)

Ahmad Al-Hanbali [DEA RSD UNSA, 03/01/03–09/30/03]
 Diman Barman [Boston University, USA, 06/01/03–08/31/03]
 Wojciech Paszke [University of Zielon Gora, Poland, 08/27/03–10/15/03]
 Alexander Verbenko [St Petersburg Polytechnical University, Russia, 04/05/03–05/05/03]

2. Overall Objectives

The area of modeling, performance evaluation and control of computer systems and communication networks is the scene of various developments both from a theoretical and from an application standpoint. Several formalisms are used in the project including queueing network theory, game theory and Markov decision process theory.

Research activities in 2003 have focused on the following issues:

- performance evaluation of wireless and mobile networks within a research grant from FRANCE TELECOM R&D and CEFIPRA, a French-Indian collaboration
- radio planning and resource allocation in geo-stationary satellite systems within a research contract with ALCATEL SPACE
- 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 ARC PRINXNET
- mathematical modeling of TCP supported by ARC TCP and by PAIS POLONIUM and 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 PAIS POLONIUM and VAN GOGH
- analysis of service differentiation (in particular priority queueing) in cooperation with LYAPOUNOV INSTITUTE
- performance evaluation of distribution content networks using stochastic fluid models.

3. Scientific Foundations

The main mathematical tools and formalisms used in MISTRAL 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
- Satellite communications: IP over satellite links, planning and resource allocation.

5. Software

5.1. Allegro, a multimedia traffic generator

Participants: Maria Ladoue, Philippe Nain, David Sagnol.

Key words: *Audio and video traffic models, udp traffic generator.*

In 2003, M. Ladoue and D. Sagnol pursued the development of ALLEGRO, a multimedia traffic generator. The initial plan was to integrate this multimedia traffic generator into our Web traffic generator WAGON; for a variety of reasons it has been decided to develop a new tool, independent of WAGON. ALLEGRO is a Java tool aimed at generating realistic background traffic that simulates voice over IP, radio and video-on-demand applications.

ALLEGRO 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.)
- An 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/IP traffic that is representative of Internet traffic.

To make UDP traffic generator to behave more friendly with other types of traffic (and in particular IP traffic) a TCP-Friendly algorithm has been implemented whose mission is to regulate the transmission of packets in case of network congestion.

ALLEGRO supports the new version of Internet Protocol (IPV6).

These developments are carried out within the RNRT VTHD++ project (cf. section 7.4).

6. New Results

6.1. Quantitative analysis of protocols

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

Key words: *tcp, fec, DiffServ, red, message discarding.*

6.1.1. *Tcp protocol*

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

6.1.1.1. *Multi-level analysis of Tcp traffic*

In [28] we propose level-dependent mathematical models for the analysis of TCP/IP networks in presence of non-persistent sessions. Three types of models are developed: packet-level, session-level and system-level models.

At the packet-level we characterize the packet arrival process at the bottleneck node and calculate the packet loss probability using a fixed point approach. In particular, we study by simulation under which conditions the multiplexed traffic is close to Poisson. At the session-level, using the fluid model approach and conditioning on the number of loss instants, we calculate the average transfer time of TCP flows as a function of the packet loss probability and the parameters of TCP. We show that the expected latency given a packet has been lost, is not monotone with respect to the file size. In [40] we suggest how to rectify this deficiency of the current TCP. Finally, at the system-level we use the $M/G/\infty$ model to derive the distribution of the number of active sessions, and compare it with the processor-sharing model.

In order to compute the performance of both short and persistent TCP sessions, both session-level and packet-level aspects have to be taken into consideration. To that end we carry out in [29] an analysis, via NS simulations, of the aggregated packet arrival process to a bottleneck node generated by multiplexed TCP flows. We qualitatively explain the shape of the packet inter-arrival time distribution and investigate the autocorrelation function of the arrivals. We provide conditions under which the packet inter-arrival time distribution is close to exponential and show how these conditions scale when the network capacity becomes large. For the case of a packet arrival process close to Poisson, we develop a fixe-point based model which allows us to compute the packet loss probability and the bottleneck link utilization in presence of both short and long-lived sessions.

6.1.1.2. *Differentiation between short and long-lived Tcp sessions*

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 authors have advocated the use of scheduling policies that would favor short jobs over long ones. The LAS (Least Attained Service) scheduling policy is one of them.

In [41] we propose a packet-level stateless, threshold based scheduling mechanism for TCP flows, called RuN2C. We describe an implementation of this scheme, which has the advantage of being TCP compatible and progressively deployable. We compare the behavior of RuN2C with that of LAS-based mechanisms through both analytical models and simulations of TCP for networks with tail drop buffers. We compute the expected response time of RuN2C conditioned on a given flow size (the performance measure used in previous studies), and study the impact of scheduling mechanisms on extreme values of response times as well as on the stability of the network.

We show that RuN2C has a very beneficial effect on the delay of short flows, while treating large flows like the current TCP. In contrast, we identify cases where LAS-based schemes exhibit pathological behavior.

6.1.1.3. *Tcp enhancements*

In TCP connections the loss of some segments has more impact on the performance of the connection (e.g. goodput) than the loss of other segments. The former segments are (i) connection establishment segments, (ii) segments sent when the connection has a small window, and (iii) segments sent after a time-out or a fast retransmit. We call these segments “vulnerable” segments (or packets).

It has been shown recently that by marking these segments with a higher priority, and by implementing the priority using a DiffServ architecture, the performance of the TCP connection considerably improves. This requires that network layer elements be aware of transport layer information, i.e. of the state of the TCP connection. In [20] we show through NS simulations that one can achieve prioritization of sensitive segments without any use of transport layer information, thus simplifying the implementation of DiffServ marking of TCP packets.

6.1.1.4. *Red (Random Early Drop)*

An important objective in the design of RED (Random Early Drop) has been to increase fairness between short and long lived TCP sessions. It has been believed that the drop probability of a packet in RED does not depend on the size of the file to which it belongs. In [14][23] we study the fairness properties of RED, where fairness is defined with respect to the size of the transferred file. We focus on short-lived TCP sessions. Our findings are that (i) in terms of loss probabilities, RED is unfair: it favors short sessions over long ones, and (ii) RED is fairer in terms of the average throughput of a session (as a function of its size) than in terms of loss probabilities. We study in [14][23] various loading regimes, with various versions of RED, and show that the unfairness of RED is the most pronounced at light loads.

6.1.2. *Fec (Forward Error Correction)*

Participants: Eitan Altman, Alain Jean-Marie.

For the past several years we have been investigating the performance of networks in the presence of added redundancy (forward error correction, FEC in short) and losses due to queueing congestion. FEC permits to recover from packet loss at the cost of increasing the network load. We have previously studied the tradeoff between the gain obtained by the decrease of losses due to the loss recovery that the additional redundancy allows, and the increase in congestion losses due to the additional load that the redundancy incurs. We pursue this line of research in [32], where we identify a large improvement in performance if in addition to adding FEC one also uses interleaving of packets. Thus packets that are originally transmitted consecutively become spaced further apart. The intuitive reason for the improvement is that spacing packets allows losses to seem less bursty, which is better for FEC. In [15] we pursue the investigation of FEC applied to more complex loss processes in which packets may be dropped not only due to congestion but also due to noisy channels.

6.1.3. *Early and selective discarding*

Participant: Eitan Altman.

In many applications, the loss of one packet in a block of packets makes the whole block useless. We call this a “corrupted block”. Selective discarding is an approach in buffer management, that permits an increase of the goodput by rejecting packets that belong to corrupted messages. Early discarding is another approach that permits an increase of the goodput by predicting corruption of a message, and by discarding all packets of a message before it has been corrupted. In the last three years, we have conducted intensive evaluations of these discarding schemes and our findings are now available in [16][17]. In [30] we analyze a new discarding scheme in the presence of reactive traffic. In this scheme, discarding is accompanied by a backoff of the source which then goes into a silent period before reemitting a corrupted block.

6.2. Wireless networks

Participants: Eitan Altman, Konstantin Avrachenkov, Rachid El-Azouzi, Tania Jiménez, Robin Groenevelt, Nidhi Hegde, Daniele Miorandi, Philippe Nain, Balakrishna Prabhu, Corinne Touati.

Key words: *ieee 802.11, ad-hoc networks, Umts, slotted Aloha, multi-spot satellite communications.*

6.2.1. *Cellular networks*

Participants: Eitan Altman, Nidhi Hegde.

Traditional definitions of capacity of CDMA networks are either related to the number of calls they can handle (pole capacity) or to the arrival rate that guarantees that the rejection rate (or outage) is below a given fraction

(Erlang capacity). We extend the latter definition in [22] to other quality of service (QoS). We consider best-effort (BE) traffic sharing the network resources with real-time (RT) applications. BE applications adapt their instantaneous transmission rate to the available bandwidth and thus need not be subject to admission control or outages. The appropriate QoS is the average delay. The delay aware capacity is defined as the arrival rate of BE calls that the system can handle such that their expected delay is bounded by a given constant. We compute both the blocking probability of the RT traffic having an adaptive Grade of Service as well as the expected delay of the BE traffic for an uplink multi-cell WCDMA system. This yields the Erlang capacity for the former and the delay aware capacity for the latter.

6.2.2. *Wlan access*

Participants: Eitan Altman, Rachid El-Azouzi, Tania Jiménez, Daniele Miorandi.

The ALOHA protocol, and its slotted version, are the first random access protocols and are still used in satellite and wireless communications. They are based on feedback from the channel that allows each transmitting source to know whether there has been no packet transmission, one successful packet transmission, or packet collisions (and was thus unsuccessful). Packets involved in collisions have to be retransmitted later. We study in [21] the distributed choice of the retransmission probabilities in a slotted ALOHA. Both the cooperative team problem as well as the noncooperative game problem are considered. A Markov chain analysis is used to obtain optimal and equilibrium retransmission probabilities and throughput. We then investigate the impact of adding retransmission costs (which may represent the disutility for power consumption) on the equilibrium and show how this pricing can be used to make the equilibrium throughput coincide with the optimal team throughput.

In [39], we study the effect of TCP feedback traffic in IEEE 802.11b-based WLANs. In particular, we present an analytical model which allows the evaluation of the impact of the delayed acknowledgments option on TCP throughput. Furthermore, we investigate the impact of such mechanism on the session delay for short TCP transfers. We show that, by carefully tuning some system parameters, both bulk TCP throughput and session delay may benefit from the use of delayed ACKs.

6.2.3. *Ad hoc networks*

Participants: Eitan Altman, Tania Jiménez, Robin Groenevelt, Philippe Nain.

6.2.3.1. *Static ad hoc networks*

We study the performance of TCP over a static multihop network that uses IEEE 802.11 protocol for access. For such networks it is known that TCP performance are mainly determined by the hidden terminal effects (and not by drop probabilities at buffers) that limits the number of packets which can be transmitted simultaneously in the network. We propose in [24][25] new approaches for improving the performance based on thinning the ACK streams that competes over the same radio resources as the TCP packets. In particular, we propose a new delayed ACK scheme in which the delay coefficient varies with the sequence number of the TCP packet. Through simulations we show that ACK thinning increases TCP throughput substantially more than previous improvement methods.

6.2.3.2. *Relaying in mobile ad hoc network*

Mobile ad hoc networks are characterized by a lack of fixed infrastructures and by the mobility of its components (nodes). Recent studies indicate that nodes can take advantage of their mobility to communicate (data transfers, etc.). This is achieved by using (mobile) intermediary nodes between a sender and a destination as relay nodes. In [42] nodes move according to independent Brownian motions on a line and we compute the expected time before a message reaches its destination when node relaying is used.

6.2.4. *Satellite communications*

Participants: Eitan Altman, Corinne Touati.

Jointly with J. Galtier from MASCOTTE team and with ALCATEL SPACE (Toulouse), we have studied a multi-spot geostationary satellite system for which a manager assigns bandwidth between service providers

(operators) that operate in different geographical areas. An assigned unit of bandwidth may correspond to different amounts of throughput, depending on many factors, and in particular on radio propagation conditions. Indeed, during bad weather conditions in an area, a local operator may have to use a larger part of its bandwidth for redundant information (a higher coding rate for error correction), and thus the effective throughput of information decreases. Therefore, if the objective was to maximize the global throughput, it would become non-profitable to assign bandwidth to operators in areas that suffer from bad weather conditions. We were thus asked by ALCATEL SPACE to first propose bandwidth assignment schemes that are fairer than existing schemes and do not systematically penalize operators that suffer from bad weather conditions. We provide in [35] an efficient algorithm that achieves a fair and Pareto optimal bandwidth assignment through a discrete optimization problem of carrier assignment, where the degree of fairness can be controlled. We then considered the slot assignment problem that corresponds to the computed fair assignment of carriers. Radio interference imposes constraints on the slots that can simultaneously be assigned in different cells that have the same frequency. The problem is shown to be NP-complete, which motivates us to search for a heuristic solution approach. We describe in [34] a heuristic solution based on simulated annealing and show how to speed up the convergence of the algorithm.

6.2.5. *Threshold based channel switching policy for Tcp over Umts*

Participants: Eitan Altman, Konstantin Avrachenkov, Balakrishna Prabhu.

UMTS is the third generation of cellular wireless networks which provides high-speed data access along with real-time voice calls. On the UMTS downlink, data can be transferred through dedicated channels (DCH) or a shared channel (FACH). Dedicated channels offer higher transfer speeds but require a setup time which is significant (of the order of 250ms). Shared channels, on the other hand, have a low setup time and also low transfer speeds. For sporadic traffic (i.e. short files/transfers) it is efficient to use the shared channel. However, for long data sessions it may be better to allocate a dedicated channel. In [33] we propose a threshold policy to determine which sessions should use the dedicated channels. Initially, we use the FACH for a given connection. Then, if we get an indication that the current burst might be long (for example, we observe a long queue from that source), then beyond some threshold we shall try to allocate a DCH to that connection (if any available). We also present and evaluate the performance of algorithms in which a timer is set when the queue size falls below a given threshold and the connection is on DCH. The use of timer allows a connection to remain for a longer duration on DCH and thus improves performance.

6.3. Content distribution networks

Participants: Florence Clevénot, Philippe Nain.

Key words: *Web cache, P2P network, video-on-demand, fluid model.*

6.3.1. *Peer-to-peer systems*

Peer-to-peer (P2P) systems exhibit two types of events: user connection/disconnection events, and requests for multimedia files or Web objects. In [37] we proposed a simple mathematical model, where request streams are represented as fluid flows modulated by user arrivals/departures, and we applied it to analyze Squirrel, a recent P2P cooperative Web cache. This work differs from [38] in the sense that clients and caches are now the same entities, so the global request rate now depends on the active node population. Our 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 our model. In addition, our generic analysis does not restrict to Squirrel but also applies for any P2P file sharing system based on distributed hash tables (such as CAN, Chord or Pastry for example), provided documents are not replicated in the system.

6.4. Game theory applied to networking

Participants: Eitan Altman, Rachid El Azouzi, Tania Jiménez, Corinne Touati.

Key words: *Noncooperative games, cooperative games, hierarchical optimization, multicriteria.*

6.4.1. *Noncooperative games in networks*

In an idealistic vision of an intelligent network that controls routing, congestion, transmission rates, etc. of its users, optimization methodology could be used to maximize utilities or benefits. However the main trend in networking is to simplify the network and to use distributed and decentralized protocols. This often leaves to the users or applications the task to determine the congestion and routing control they use. An appropriate methodology that describes and models well decentralized decision making by many individual entities (agents) is non-cooperative game theory, and the Nash equilibrium is the appropriate solution concept of that optimization. We have been pursuing in the last three years an intensive research on the use of game theory to study such networks within a research contract with FRANCE TELECOM R&D. In addition to the multi-agent aspects, inherent to game theory, we are interested in multicriteria aspects which means that each agent might have several objectives and also several types of control actions. We are also interested in hierarchical aspects of such multi-agent problems, and on the impact of a network manager on the equilibrium that could be achieved by the network users.

In [13] we study a well known Braess paradox related to this hierarchical optimization which shows that when upgrading a network by adding a link, the resulting equilibrium may exhibit larger delays for all users. We present guidelines to avoid the Braess paradox when upgrading a network. We furthermore present conditions for the delays to be monotone increasing in the total demand.

We investigate the multicriteria aspect of equilibrium in networking games in [18]. We study noncooperative routing in which each user is faced with a multicriterion optimization problem, formulated as the minimization of one criterion subject to constraints on others. We address the questions of existence and uniqueness of equilibrium. We show that equilibria indeed exist but uniqueness may be destroyed due to the multicriteria nature of the problem. We obtain uniqueness in some weaker sense under appropriate conditions: we show that link utilizations are uniquely determined at equilibrium. We further study the normalized constrained equilibrium and apply it to pricing.

Finally, we study a problem that involves all three aspects of networking games: multi-agent, multicriterion and hierarchical aspects. We present in [31] a competitive model that describes the interaction between competing telecommunications service providers (SPs), their subscribers, and a network owner. Competition takes place in pricing as well as in terms of the quality of service (QoS) each SP offers. The subscribers' demand depends not only on the price and QoS of that SP but also upon those of its competitors. We establish conditions for existence and uniqueness of the equilibria, compute them explicitly and characterize their properties.

6.4.2. *Cooperative games in networks*

We have been studying in the past years the problem of assigning bandwidth fairly to calls that have minimum bandwidth requirements. The fairness concepts we consider are based on the Nash bargaining concept from cooperative games. In previous years we have studied the theoretical part of this problem by transforming it to an equivalent optimization problem. As a next step, our goal is to provide a general computational tool for solving the optimization problem. In [36], we propose such a tool based on Semi-Definite Programming (SDP). The advantage of our approach is that many appealing complex objective functions related to fairness criteria are special cases of our formalism. Therefore, such optimization problems can be solved in an automatic manner provided that a SDP package is available to the network manager. In particular, our approach gives the solutions of max-min and proportional fairness assignments, and is suitable for both ATM and Internet contexts.

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

Participants: Eitan Altman, Konstantin Avrachenkov, Philippe Nain.

6.5.1. *S-modular games and power control*

Key words: *S-modular games.*

Participant: Eitan Altman.

In [12], we show how centralized or distributed power control algorithms in wireless communications can be viewed as S-modular games with coupled policy sets (coupling is due to the fact that the set of powers of a mobile that satisfy the SIR constraints depends on powers used by other mobiles). This sheds new light on convergence properties of existing synchronous and asynchronous algorithms and allows us to establish new convergence results of power control algorithms. Furthermore, known properties of power control algorithms allow us to extend the theory of S-modular games and obtain conditions for the uniqueness of the equilibrium and convergence of best response algorithms independently of the initial state.

6.5.2. Priority queues and perturbed Markov chain

Key words: *Priority queues, Markov chain, singular perturbations.*

Participant: Konstantin Avrachenkov.

6.5.2.1. Priority queueing with randomized push-out

A non-preemptive priority queueing system with a finite buffer is considered in [27]. We study a randomized push-out buffer management mechanism, which allows an efficient control of the loss probability of priority packets. Numerically stable recursive formulas for the elements of the stationary distribution are obtained using a generating function approach. Explicit expressions are found for the standard non-randomized push-out scheme. When comparing the randomized push-out scheme to the threshold based push-out scheme, we find that the former scheme is much easier to tune than the latter. The proposed scheme can be applied to the Differentiated Services of the Internet.

6.5.2.2. 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 [26] we suggest a method for computing the most significant singular matrices in these expansions in a way that highlights the system dynamics in various time-scales. Moreover, despite the fact that this method does not require the prior knowledge of the order of the pole, it is numerically stable.

6.5.3. Stability of queues

Key words: *Stability, Lindley equation, Markov chain with continuous state-space.*

Participant: Philippe Nain.

6.5.3.1. Stability analysis of a Red-like queue

In collaboration with A. Makowski (Univ. Maryland, USA) and P. Robert (RAP team, INRIA Rocquencourt), P. Nain has determined the stability condition of a RED-like buffer [43]. Considered is an GI/M/1 queue, where an arriving customer is discarded with a probability that depends on some estimate of the queue-size (a generalization of the so-called RED function). The stability condition is obtained by studying a two-dimensional Markov chain through the combination of bounding and pathwise arguments. In particular, it is shown that the queue is always stable when the standard RED function is used.

7. Contracts and Grants with Industry

7.1. Collaboration with Alcatel Space

Participants: Sara Alouf, Eitan Altman, Corinne Touati.

This has been the last year of a two-year contract between ALCATEL SPACE in Toulouse and the MISTRAL and MASCOTTE teams at INRIA. Our contribution has been to propose a framework of resource allocation for satellite systems that guarantees optimality and fairness in the radio planing phase. We have designed algorithms to solve the problem of slot assignment so as to maximize the amount of assigned demand taking into account interference constraints (see Section 6.2.4).

7.2. Collaboration with France Telecom R&D on game theory

Participants: Eitan Altman, Rachid El-Azouzi.

In this three-year contract with FRANCE TELECOM R&D at Issy-Les-Moulineaux (signed in December 2000), we have contributed to the theory of hierarchical multi-agent optimization in networks in a competitive setting. We have considered both competition between users for routing and flow control problems, as well as the competition between service providers that have to design pricing strategies as well as strategies for the quality of services they provide. Our analysis is based on non cooperative theory and on the Nash equilibrium concept (see Section 6.4).

7.3. Collaboration with France Telecom R&D on Umts

Participants: Eitan Altman, Konstantin Avrachenkov, Rachid El-Azouzi, Nidhi Hegde, Bala Prabhu.

A new three-year contract with FRANCE TELECOM R&D at Issy-Les-Moulineaux is about to be signed, although we have already been working on it for the last two years. In traditional telephone networks, the standard capacity definition (Erlang capacity) is defined as the arrival rate that guarantees rejection rate smaller than some small number (e.g. 1 percent). We develop new notions of capacity adapted to UMTS that we use to design and optimize the network. Another contribution is the solution of rate control problems combined with power control; our results are currently being patented jointly with FRANCE TELECOM R&D (see Section 6.2.1).

7.4. Rnrt Vthd++

Participants: Maria Ladoue, Philippe Nain, David Sagnol.

MISTRAL is in charge of developing and deploying the ALLEGRO software within the VTHD++ project (see <http://www.vthd.org/> for general information on the VTHD project). ALLEGRO is a multimedia traffic generator (see Section 5.1) that creates on demand a realistic background traffic on the VTHD platform. The VTHD++ project is the successor of the VTHD project, in which MISTRAL deployed WAGON, a Web traffic generator, on the VTHD platform (see previous activity reports).

Both softwares ALLEGRO and WAGON run on a hundred dedicated workstations connected to the VTHD platform, deployed at 8 different geographical sites. Several test campaigns have already qualitatively and quantitatively assessed the performance of these traffic generators.

Monitoring tools (Cricket, Smokeping) have been installed at INRIA in Rocquencourt and in Sophia Antipolis, with the collaboration of N. Sayer, an INRIA engineer for the VTHD++ project.

8. Other Grants and Activities

8.1. International initiatives

8.1.1. Network of Excellence: Euro-Ngi

MISTRAL 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”.

8.1.2. Collaboration with India: Cefipra

Since April 2003 MISTRAL 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. 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 (who completed his Ph.D. thesis with IISc under the supervision of Prof. A. Kumar) as well as travels between

France and India. This collaboration is further strengthened by the presence at INRIA of B. Prabhu (a Ph.D. student in MISTRAL), who completed his Master degree at IISc under the guidance of Prof. A. Chokalingam.

8.1.3. *Collaboration with the Netherlands: Pai Van Gogh*

MISTRAL, together with three Dutch teams:

- a team from CWI (S. Borst, M. Mandjes, R. Nunez-Queija)
- a team from Eindhoven University (O. J. Boxma, J. Resing, B. Zwart)
- 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 just been extended for another year.

8.1.4. *Collaboration with Poland: Pai Polonium*

MISTRAL, together with INRIA teams METALAU (J.-P. Quadrat) and SOSSO (P.-A. Bliman), are involved in a PAI Polonium in partnership 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”.

8.1.5. *Collaboration with Russia: Lyapounov Institute Projet*

MISTRAL, together with a team of St. Petersburg State Polytechnic University (N. Vilchevsky, G. Shevlyakov and A. Verbenko), forms a Lyapunov Institute project. The goal of this project is to analyse priority queues with finite buffer and to apply the results to the *Diffserv* Internet architecture.

8.1.6. *Collaboration with the USA: Nsf Itr*

MISTRAL 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, MISTRAL is associated with UMass in a five-year NSF ITR project on “QoS in the future Internet”. This project finances visits of members of MISTRAL to UMass. In 2003, P. Nain visited twice UMass in this framework.

8.2. National initiative

MISTRAL is involved in two research initiatives (Actions Spécifiques – AS) of CNRS, one on “Dynamical Systems and Modeling of Algorithms” (AS 80) and another one on “Random Models and the Performance of Distributed Systems” (AS 182).

8.3. INRIA new investigation grant

8.3.1. *Arc Prixnet*

MISTRAL is a member of ARC PRIXNET² which aims at developing, implementing and comparing new pricing schemes for telecommunication networks. Our partners are: team ARMOR from INRIA, FRANCE TELECOM R&D, PRiSM Lab. (Univ. Versailles) and IBM T.J. Watson Research Center, USA.

8.3.2. *Arc Tcp*

Since February 2002 MISTRAL 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. This ARC is composed of six INRIA teams (ARMOR, HIPERCOM, MISTRAL, PLANETE, TREC, RAP), one team from LIRMM, a CNRS/Univ. Montpellier research laboratory, three teams from FRANCE TELECOM R&D (Issy-Les-Moulineaux, Lannion, Sophia Antipolis) and one team from EPFL.

²<http://www.irisa.fr/armor/Armor-Ext/RA/prixnet/ARC.htm>

³http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/ARC_TCP.html

ARC TCP has 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 from researchers and interns from outside the group. The second ARC TCP Workshop took place on November 5-7, 2003 at Ecole Normale Supérieure in Paris⁴ and gathered over 50 participants. In addition to ARC TCP members, the following distinguished researchers have given lectures during this workshop: F. Kelly (University of Cambridge; plenary lecture), R. Srikant (University of Illinois at Urbana Champaign, plenary lecture), L. Massoulié (Microsoft Research, Cambridge) and A. Kumar (IIT, India).

8.4. Visiting scientists

8.4.1. Europe

K. Galkowski (University of Zielona Gora, Poland, 09/12/03–09/22/03), G-J. Franx (Vrije University of Amsterdam, Netherlands, 12/12/02–01/02/03), G. Koole (Vrije University of Amsterdam, Netherlands, 04/28/03–05/09/03), C. Lindemann (University of Dortmund, Germany, 10/18/03–10/21/03), B. Miller (Russian Academy of Sciences, Moscow, Russia, 11/20/03–01/31/04), E. Nyberg (Helsinki University of Technology, Finland, 01/20/03–01/26/03), R. Nunez-Queija (CWI, Amsterdam, Netherlands, 03/10/03–03/14/03), W. Paszke (University of Zielona Gora, Poland, 08/27/03–10/15/03), G. Shevlyakov (St. Petersburg State University, Russia, 04/12/03–04/19/03), A. Verbenko (St Petersburg Polytechnical University, Russia, 04/05/03–05/05/03).

8.4.2. America

T. Başar (University of Illinois, USA, 03/18/03–03/31/03), M. Krunz (University of Arizona, Tucson, USA, 04/15/03–08/05/03), H. Kushner (Brown University Providence, USA, 04/05/03–05/04/03), Z. Liu (IBM, New York, USA, 07/21/03–07/25/03), R. Marquez-Contreras (University of Los Andes, Mérida, Venezuela, 08/01/03–10/08/03), D. Figueiredo (Univ. of Massachusetts, Amherst, USA, 10/27/03–10/31/03), C. Rosenberg (University of Purdue, USA, 06/02/03–06/03/03), S. Kalyanaraman (Rensselaer Polytechnic Institute, Troy, USA, 03/12/03–03/17/03).

8.4.3. Maghreb and Middle-East

U. Yechiali (University of Tel Aviv, Israel, 04/07/03–04/14/03).

8.4.4. Asia

H. Kameda (University of Tsukuba, Japan, 07/18/03–08/06/03), A. Kumar (IIS, Bangalor, India, 10/06/03–12/01/03), J. Li (University of Tsukuba, Japan, 03/02/03–03/17/03).

8.4.5. Oceania

M. Haviv (University of Sidney, Australia, 02/10/03–02/15/03).

8.5. Visits of Mistral staff to other research institutions

E. Altman spent one month (January 2003) at the University of Los Andes in Mérida, Venezuela.

K. Avrachenkov visited the University of South Australia for four months (May-August), where he worked on his book “Analytic Perturbation Theory and its Applications,” co-authored with J. Filar and P. Howlett), the National University of Singapore, St.Petersburg State Polytechnic University and Lyapunov Institute in Russia, CWI and the University of Twente, The Netherlands, the University of Liverpool, United Kingdom.

U. Ayesta visited Prof. A. Piunovskise twice at the University of Liverpool for a period of one week (in April and in November.), and Prof. S. Aalto at the Technical University of Helsinki for two weeks (11/2003).

P. Nain visited the University of Massachusetts twice (in January and in November) and IBM T. J. Watson Research Center both at Hawthorne and at Yorktown Heights, USA (November).

C. Touati spent a summer internship at IBM T. J. Watson Research Center at Hawthorne, USA. Since October 2003, C. Touati holds a postdoctoral position at the University of Tsukuba, Japan.

⁴<http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/Workshop2/index.html>

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 of *Performance Evaluation* (Special Issue on selected papers from WiOPT'03 workshop) with R. Mazumdar and P. Nain, and of a Special Issue of *IEEE Journal of Selected Area in Communications* on Ad Hoc Networks.

P. Nain is an Associate Editor of the following journals: *Journal of Applied Mathematics*, *Operations Research Letters*, *Performance Evaluation*. He is a Guest Co-Editor of *Performance Evaluation* (Special Issue on selected papers from WiOPT'03 workshop) with E. Altman and R. Mazumdar.

9.1.2. Participation in technical program committees

E. Altman was a program co-chair of the Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOPT'03; INRIA Sophia-Antipolis, France, March 3-5, 2003). He was a program committee member of the following conferences: IEEE INFOCOM 2003 (April 1-3, San-Francisco), Personal Wireless Communications Conference (PWC 2003; September 23-25, 2003, Venice, Italy), 1st International Working Conference on Performance Modelling and Evaluation of Heterogeneous Networks (HET-NETs'03; July, West Yorkshire, U.K.).

K. Avrachenkov was a program committee member of the following conferences: 5th International Congress on Industrial and Applied Mathematics (ICIAM; Sydney, Australia, July 7-11, 2003), Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOPT'03; INRIA Sophia-Antipolis, France, March 3-5, 2003).

P. Nain was a program committee member of the following conferences: IEEE INFOCOM 2003 (April 1-3, San-Francisco, USA), ACM SIGMETRICS (June 10-14, San Diego, USA), Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOPT'03; INRIA Sophia-Antipolis, France, March 3-5, 2003).

9.1.3. Conferences, meetings and tutorial organization

- E. Altman and K. Avrachenkov participated in the organization of the Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOPT'03; INRIA Sophia-Antipolis, France, March 3-5, 2003).
- E. Altman, K. Avrachenkov and P. Nain organized the 2nd ARC TCP Workshop (ENS, Paris, November 5-7).
- P. Nain organized the Evaluation Seminar of INRIA Research Theme 1B on "Networks and Telecommunications"⁵ (Jouy-en-Josas, October 22-23, 2003).

9.1.4. Participation to thesis committees

E. Altman participated in the Ph.D. thesis committees of C. Touati (September 26, 2003, UNSA), and A. Proutière (November 4, 2003, Ecole Polytechnique).

⁵<http://www-sop.inria.fr/mistral/eval1B2003/eval1B.html>

- A. Jean-Marie participated in the Ph.D. thesis committee of Y. Calas (December 19, 2002, Univ. of Montpellier).
- P. Nain participated in the Ph.D. thesis committees of N. Malouch (January 3, 2003, UNSA), D. Gauchard (April 25, 2003, Univ. Paul Sabatier, Toulouse), C. Touati (September 26, 2003, UNSA), and in the “Habilitation” thesis committee⁶ of D. Kofman (December 22, 2003, ENST, Paris).

9.1.5. Research administration

- **A. Jean-Marie**
 - was the Head of the Computer System Department of LIRMM, University of Montpellier II, until October 24, 2003
 - 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 in Computer Science at the University of Montpellier II.
- **P. Nain**
 - is a member of the Expert Committee in Computer Science⁷ of UNSA
 - is in charge of the Master Program on “Networking and Distributed Systems” (DEA 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 7.3⁸ on “Computer Performance Modeling and Analysis”. P. Nain is the treasurer of this working group.

9.1.7. Ph.D. thesis

The following Ph.D. theses were defended in 2003:

- N. Malouch on January 6, 2003 [9]
 C. Touati on September 26, 2003 [10].

9.2. Teaching

- A. Jean-Marie taught a course on “Random Models in Combinatorics and Networking” (DEA Paris 6/ENS/X ALGO) and a course on the “Control of Telecommunication Networks” (DEA IRO, 12H), both at the University of Paris 6.
- P. Nain taught a course on “Modeling and Performance Evaluation of Networks” at UNSA (DEA RSD, 24H) and at INSTITUT EURECOM (15H), and a course on “Control of Telecommunication Networks” at the University of Paris 6 (DEA IRO, 12H).

⁶Habilitation à Diriger des Recherches (HDR)

⁷27ième Section de la Commission des Spécialistes

⁸<http://www-net.cs.umass.edu/wg7.3/>

9.3. Conference and workshop committees, invited conferences

- E. Altman was an invited speaker in the Research Seminar on Mobile Networks: Quality of Service and Cross-Layer Issues, KTH Center for Wireless Systems, Kista, Stockholm, Sweden October 3, 2003 (held in conjunction with QofIS 2003 Workshop). He gave lectures at the Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOPT'03; INRIA Sophia-Antipolis, France, March 3-5, 2003), Personal Wireless Communications Conference (PWC 2003; September 2003, Venice, Italy), MADNET'03 (Sophia-Antipolis, March 2003) and at the 18th International Teletraffic Congress (ITC; Berlin, August 31 - September 5, 2003).
- K. Avrachenkov gave a presentation at the 5th International Congress on Industrial and Applied Mathematics (ICIAM'03; Sydney, Australia, July 7-11, 2003), the 4th International Conference on the Numerical Solution of Markov Chains (NSMC'03; Urbana, IL, September 3-5, 2003) and at the 2nd ARC TCP Workshop (ENS Paris, November 5-7, 2003).
- U. Ayesta gave a presentation at the 18-th International Teletraffic Congress (ITC; Berlin, August 31 - September 5, 2003) and at the 2nd ARC TCP Workshop (ENS Paris, November 5-7, 2003).
- F. Clévenot gave a presentation at the 8-th Atelier d'Evaluation de Performances (May 12-16, Reims, France) and at the 2nd ARC TCP Workshop (ENS Paris, November 5-7, 2003).
- R. El-Azouzi presented a paper at the 18th International Teletraffic Congress (ITC; Berlin, August 31 - September 5, 2003), Personal Wireless Communications Conference (PWC 2003; September 2003, Venice, Italy), and at the 5th Congress of the French Society of Operations Research (ROA-DEF'2003; February 26-28, Avignon, France).
- N. Hegde presented a paper at IEEE Wireless Communications and Networking Conference (WCNC; New Orleans, LO, USA, March 16-20, 2003).
- A. Jean-Marie participated in a meeting of AS 80 on "Dynamical Systems and Modeling of Algorithms" (ENST, Paris, 9-10/12/03) and to a meeting of AS 182 "Random Models and the Performance of Distributed Systems" (17/11/03) (see Section 8.2 for more information).
- P. Nain gave a seminar at IBM T.J. Watson Research Center (November 17, 2003). He participated in the Program Committee Meeting of the ACM SIGMETRICS 2003 Conference (Florham Park, NJ, USA, January 18, 2003)
- B. Prabhu presented a poster at IEEE VTC2003-Fall (Orlando, FL, USA, October 2003) and a paper at the 2-nd ARC TCP Workshop (ENS Paris, November 5-7, 2003)
- C. Touati presented a paper at the 18th International Teletraffic Congress (ITC; Berlin, August 31 - September 5, 2003).

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- [10] C. TOUATI. *Fairness Principles Applied to Telecommunication Networks*. Ph. D. Thesis, University of Nice-Sophia Antipolis, September, 2003.

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