## IMPORTANT INSTRUCTIONS TO APPLICANTS

1. IFCAM will consider and support proposals for collaborative advanced research between scientists / institutions in India and scientists / institutions in France. Proposals can be made in any area of applied mathematics (interpreted broadly to include applications in science and engineering provided they have a non-trivial mathematical content). The proposal should be original, collaborative and of high scientific quality.

2. **Last date** for receipt of proposals at IFCAM is **December 15, 2012**.

3. A proposal should be jointly submitted by one Principal Collaborator in India and one Principal Collaborator in France. The two Principal Collaborators shall be responsible for the conduct of the project. In addition to the two Principal Collaborators, there may also be one or more Joint Collaborator(s) from India and France. The Joint Collaborators may be from the same institutions as the respective Principal Collaborators or from other institutions. By submitting the proposal to IFCAM, the Principal Collaborator certifies that all other collaborators have given their consent. Any change of Principal Collaborator(s) or Joint Collaborator(s) or the institution(s) where the work is being carried out would be possible only with the permission of IFCAM.

## IMPORTANT

Proposals should be submitted by email (ifcam@math.iisc.ernet.in) as a pdf document. In addition one complete set should be submitted as a hard copy (complete paper set) with the originals of the cover page and certificates signed by the Heads of Institutions.

The proposal should contain the following items in the same order:

a) Project identification

b) Detailed Project Description (not exceeding 5000 words) and relevant data, budget estimates and planned international travels.

c) Annexure A: Biodata of each of the two Principal Collaborators containing, *inter alia,* academic qualifications & research experience along with a list of not more than 10 most significant publications during the last five years

d) Annexure-B, i.e. one certificate from the Head of the Institution of the Indian Principal Collaborator and one certificate from the Head of the Institution of the French Principal Collaborator, both certificates being on letter-head (en-tête)

**Address for submissions:**

**The Director**
**Indo-French Centre for Applied Mathematics**
**Indian Institute of Science**
**Bangalore 560 012**
**India**

**Tel: +91-80-2293 3217/8**
**Fax: +91-80-2360 5390**
**Email: ifcam@math.iisc.ernet.in**

# IFCAM PROJECT IDENTIFICATION

**PROPOSAL N°:**
**(to be filled by IFCAM)**

**TITLE in English:**
**(50 char. at most)**

Application of optimal control and game theory in communication networks

**TITLE in French:**
**(50 char. at most)**

Application de la Théorie du contrôle optimal et de la théorie des Jeux dans les Réseaux de Télécommunication

**DURATION OF THE PROJECT:** 3 years

**PRINCIPAL COLLABORATOR (Indian): Name and Affiliation**


Rajesh Sundaresan, ECE Department, Indian Institute of Science


**PRINCIPAL COLLABORATOR (French): Name and Affiliation**


Eitan Altman, INRIA Sophia-Antipolis, France


**SUMMARY (English): 10 lines max.** (10 pts font)


With fast evolving wireless technology and huge increases in wireless traffic, network engineers are faced with new challenges in scaling up the network capacity to meet demand. Centralised solutions for network protocols are often not possible, and network operators rely more and more on self organisation and decentralised control. In this project we shall propose new protocols for wireless network design based on communication and information theoretic tools on one hand, and on optimal control and game theory on the other. We plan to contribute to various technologies such as cellular networks, sensor networks, and ad hoc networks. We shall study tradeoffs between performance measures and energy efficiency.

## Part I : PROJECT DESCRIPTION and other Related Information

**The detailed description (in English) of the project should be organised within the six following items (items 110 to 160) with an overall length not exceeding 3000 words** ***(boxes will expand with increasing text length)***

### 110. Objectives of the project as bullet points:

a) In a multiserver queueing system with multiple user classes, find optimal routing strategies to minimize sum delay across user classes. The routing strategy must be oblivious to queue sizes.

b) Identify pricing and admission restrictions to attain load balancing in the above setting.

c) Identify and analyse methods to obtain balanced fractional loads in random sparse Erdos-Renyi networks. Characterize the average load in a balanced fractional assignment.

d) Devise and analyse algorithms for reaching consensus over a graph with communication constraints. The function to be reached may be a consensus function (ranking of nodes, preferential orders, time-synchronization parameters, etc.). Optimize the computations to speed up convergence to the consensus values.

e) Competition for content spread over online social networks.

f) Study of distributed algorithms for large-scale MIMO systems.

**g)** Estimation and filtering issues in wireless cellular networks

h) Study of "zero" service time continuous polling systems and application to wireless networks.

### 120. State of the art (with relevant references from major journals):

Single server and multiserver queues with cost proportional to the waiting time and individual routing were considered in [1], [2], and [3]. The price of anarchy (PoA), the gap in performance between the equilibrium strategies and the social optimum, were identified. In the multiclass multiserver queue case, some degree of centralization via dispatchers (one dispatcher for each class who minimises the corresponding class's waiting time) was studied in [4] and existence of an equilibrium and PoA were established. An even more centralised dispatching (with probabilities of sending a class i node to queue j) was studied in [5] through optimisation of a global objective function (of the mean waiting times without distinction among classes on the cost of waiting). An alternative method via admission prices, as in the Paris Metro pricing scheme [6], [7], or Tirupati pricing schemes [8], [9], charges each user a fee depending on the queue he wishes to join (higher the fee, lower the delay). The cost of waiting could now be class dependent [10]. In that case, equilibrium behaviour and pricing for various objectives were studied in [10] under decentralised routing (no dispatcher) and when there is a dispatcher for just one of the classes.

A related setting is one where a dispatcher samples two queues at random, and sends the arriving packet to the shorter of the two. With n arrivals and n queues, the largest queue size is O(log log n) with high probability as compared to O(log n / log log n) if only one queue is sampled [11], [12]. A generalisation of load balancing as an orientation was studied in [13]. Some preliminary studies fractional load sharing by the two randomly selected nodes were given in [14].

Distributed algorithms that use the "gossip" paradigm to arrive at consensus have been extensively researched because of their application in sensor networks and social networks. The state of the art is summarised in [15]. An important issue in the design of such algorithms is the rate of convergence which is dictated by the second largest (in modulus) eigenvalue of the stochastic matrix used for "gossip" averaging. Aspects of control of this eigenvalue were studied in [16] (seed values at some target nodes for consensus to desired value) and [17] (control of averaging parameters).

A related topic is one of spread of information in a network. Two recent works from this team dealt with optimal control of information spread [18] via epidemic relaying (and one-hop relaying), and co-evolution of content popularity and information spread [19] under the so-called homogeneous influence linear threshold (susceptible/infected) model. We now propose a framework for studying the competition between different content creators who can reach out to potential consumers via several social networks. Along the lines of earlier work in this area [20], [21], which consider a single social network setting, we will model the user interaction within a social network by an epidemic process. Each network will be characterized by the level of information exchange within the network (infection rate) and the popularity of the network among the population of consumers. The content creators have two options for investing in each of these networks: the initial seed population, and referral incentives for users who have viewed their content [22]. One aim of this work would be to obtain the Nash equilibrium strategies for the content providers. This would help in characterizing the allocation of total budget across the different social networks, and between the two possible advertisement strategies for the content creators.

Recently, MIMO systems with large spatial degrees of freedom are becoming popular due to their increased spectral efficiencies/throughputs, reliability and power savings [23]. The traditional view of MIMO systems is that of a point-to-point multi-antenna system with multiple inputs representing the co-located antennas at the transmitter and multiple outputs representing the co-located antennas at the receiver. One can take a more generalized view of MIMO systems where the inputs and outputs are distributed across users (distributed MIMO), which captures most multiuser communication scenarios [24]. While multiuser communication has been an interesting research topic for long, there has been a recent increase of interest in the area of distributed MIMO because of growing popularity of ad-hoc and sensor networks. Large-scale distributed MIMO in dense deployments is an emerging area. Distributed signal processing algorithms, analyses of their convergence and performance, and interference management teachniques need investigations.

For some recent work on applications of filtering and estimation theory in estimating the node population in wireless networks, we refer the reader to [25]-[27].

Polling systems are queueing systems in which a single server attends more than one queue. The systems in which arrivals are anywhere in a continuum are called continuous polling models. Previously we obtained the stationary performance of various continuous polling models using a discretisation method ([28],[29],[30]). We primarily used these results to study ferry (a moving base station) based wireless local area networks (FWLANs). While modeling FWLANs using polling models, it is assumed that the ferry stops, serves and then proceeds, upon encountering a user with a request. But in reality this is not the case. The ferry serves the users while it is moving, i.e., no extra time is spent for servicing, and this needs investigation.

[1] C. H. Bell and S. Stidham, "Individual versus social optimization in the allocation of customers to alternative servers," *Management Science*, vol. 29, pp. 831–839, 1983.
[2] M. Haviv and T. Roughgarden, "The price of anarchy in an exponential muli-server.," *Operation Research Letters*, vol. 35, pp. 421–426, 2007.

[3] E. Altman, U. Ayesta, and B. Prabhu, “Load balancing in processor sharing systems,” in *Proc. of 3rd Intnl. Conf. on Perf. Eval. Methodologies and Tools (ValueTools)*, 2008.
[4] U. Ayesta, O. Brun, and B. J. Prabhu, “Price of anarchy in noncooperative load balancing,” in *Proc. of the IEEE INFOCOM*, 2010, pp. 436–440.
[5] S. C. Borst, “Optimal probabilistic allocation of customer types to servers,” in *Proc. of ACM SIGMETRICS*, Sept. 1995, pp. 116–125.
[6] A. Odlyzko, “Paris Metro pricing for the internet,” in *Proc. of the 1st ACM conference on Electronic Commerce*, 1999, pp. 140–147.
[7] T. Mullen R. Jain and R. Hausman, “Analysis of Paris Metro pricing for QoS with a single service provider,” in *Proc. of Intnl. Workshop on* QoS *(IWQoS)*, Jun. 2001, LNCS, 2001, Vol. 2092/2001, pp. 44–58.
[8] P. Dube, V.S. Borkar, and D. Manjunath, “Differential join prices for parallel queues: social optimality, dynamic pricing algorithms and application to internet pricing,” in *Proc. of IEEE INFOCOM*, 2002, pp. 276–283.
[9] V. S. Borkar and D. Manjunath, “Charge-based control of diffserv-like queues,” *Automatica*, vol. 40, pp. 2043–2057, 2004.
[10] T. Bodas, A. Ganesh, D. Manjunath, “Load balancing and routing games with admission pricing,” *Proc. of the 2001 50th IEEE Conf. on Decision and Control and European Contr. Conf.*, pp. 249-254 Dec. 2011.
[11] M. Adler, S. Chakrabarti, M. Mitzenmacher, L. Rasmussen, “Parallel randomized load balancing,“ *Random Structures and Algorithms*, vol. 13, pp. 159-188, 1998.
[12] Y. Azar, A. Z. Broder, A. R. Karlin, E. Upfal, “Balanced allocations,” *SIAM J. Computing*, vol. 29, pp. 180-200, 1999.
[13] M. Lelarge, “A new approach to the orientation of random hypergraphs,” pp. 251-264, *Proc. of the ACM-SIAM Symposium on Discrete Algorithms*, 2012; arXiv: 1201.5335v1.
[14] B. Hajek, “Performance of global load balancing by local adjustment,” *IEEE Trans. Information Theory*, vol. 36, no. 6, Nov. 1990.
[15] D. Shah, *Gossip Algorithms*, ser. Foundations and Trends in Networking, NOW Publishers, 2009.
[16] V. S. Borkar, J. Nair, S. Nalli, “Manufacturing consent,” in *Proc. of 48th Annual Allerton Conf. on Comm. Control, and Comput.*, pp. 1550-1555, 2010.
[17] V. S. Borkar, A. Karnik, “Controlled gossip,” in *Proc. of 49th Annual Allerton Conf. on Comm. Control, and Comput.*, 2011.
[18] C. Singh, E. Altman, A. Kumar, R. Sundaresan, “Optimal forwarding in delay tolerant networks with multiple destinations,” to appear, *IEEE Trans. On Networking*.
[19] S. Venkataramanan and A. Kumar, “Co-evolution of content popularity and deliver in mobile P2P networks,” *Proc. of the 31st IEEE Infocom, 2012* (mini conference).
[20] Eitan Altman. “An epidemic game between contents in a wireless network,” *Proc. IEEE IWCSC*, France, August 2012.
[21] Eitan Altman. Game theoretic approaches for studying competition over popularity and over advertisement space in social networks. In Proc. of Valuetools Conference, Cargese, Corsicaa, 2012.
[22] Pankaj Dayama, Aditya Karnik, and Y. Narahari. Optimal incentive timing strategies for product marketing on social networks. In 11th International Conference on Autonomous Agents and Multiagent Systems (AAMAS’12) - Volume 2, 2012.
[23] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, ``Scaling up MIMO: opportunities and challenges with very large arrays,'', to appear, *IEEE Signal Process. Mag.*, Online: arXiv:1201.3210v1 [cs.IT] 16 Jan 2012.
[24] J. Wang, F. Adachi, and X. Xia, ``Coordinated and distributed MIMO [Guest Editorial]'', *IEEE Wireless Commun. Mag.*, vol. 17, no. 3, pp. 24-25, June 2010.
[25] Sara Alouf, Eitan Altman, Chadi Barakat, Philippe Nain, “Optimal estimation of multicast membership,” *IEEE Transactions on Signal Processing* 51(8): 2165-2176 (2003).
[26] Dinesh Kumar, Eitan Altman, Tamer Basar, “Exploring Wiener filter estimation of node population in a sensor network with generally distributed node lifetimes,” *WONS* 2012: 67-70.

[27] Sara Alouf, Eitan Altman, Chadi Barakat, Philippe Nain, "Estimating membership in a multicast session," *SIGMETRICS 2003*: 250-260.
[28] V. Kavitha, "Continuous polling with rerouting and applications to ferry assisted wireless LANs," *ValueTools*, 2011.
[29] V. Kavitha and E. Altman, "Continuous polling models and application to Ferry assisted WLAN," *Annals of Operations Research*, vol. 198, no.1 (2012), pp. 185-218.
[30] V. Kavitha and Richard combs, "Cross Polling with Rerouting and Applications," under revision at *Elsevier Performance Evaluation*.

## 130. Novelty of the project:

The main novelty of the project will be in the combination of advanced mathematical tools applied to engineering problems. Tools will be developed, as needed, as part of this collaboration. Specific novelties are indicated below.

Objectives (a) and (b) aim to study the benefits of having a single dispatcher and decentralized routing (with limited knowledge of queue state) for all classes and queues.

Objective (c) proposes to extend the results on existence of balanced fractional loads for sparse Erdos-Renyi random graphs.

Objective (d) will take the communication graph constraints into account while developing good algorithms that have fast convergence to consensus.

Objective (e) will identify Nash equilibrium strategies for the content providers. This would help in characterizing the allocation of total budget across the different social networks, and between the two possible advertisement strategies for the content creators.

Objective (f) will address the search for and analysis of coding and distributed decoding techniques in systems with a large number of antennas.

Objective (g) will employ game theoretic tools developed for fisheries to delay tolerant networks.

Objective (h) will deal with a novel queueing system, in which there is no extra time spent for service. The server is continuously moving in a periodic path, and picks-up a user with requests if it encounters one and has no other user already in service, and holds it until service is completed. These "zero" service systems are more realistic models of ferry based wireless LANs, conveyor belts, etc .

## 140. Work plan and methods:

Game theoretic and mechanism design tools (for pricing) will be used to address the problems of routing, load balancing, pricing, and admission control (objectives (a) and (b)).

The technique of local weak limit of graphs will be used to study the existence and uniqueness of balanced loads in sparse Erdos-Renyi graphs (objective (c)). We will try to provide a rigorous formalisation of the cavity method to compute the average load in a balanced fractional assignment. This is a special case of a convex minimization problem with constraints given by a random graph. These types of problems appear in combinatorial optimization when the variables have to be integer. We relax it here and try to extend the cavity method to this setting.

For faster consensus, methods to maximize the second largest eigenvalue of the averaging matrix subject to communication and delay constraints will be considered (objective (d)). The ODE method as applied to fluid limits in the scenario of a large number of nodes will be used to analyse co-evolution of multiple content (objective (e)).

Statistical physics and Markov chain Monte-Carlo methods will be used to address objective (f).

For objective (g), the plan is to study both the cooperative and the noncooperative cases. In the noncooperative case, cases in which one cannot directly observe the actions of the mobiles (due to the low connectivity), filtering techniques and tools from the design of fisheries will be used to estimate parameters and control the network.

For objective (h), the plan is to approximate the continuous system with a discrete polling system having 1-limited service, zero service times, and with sufficient number of queues. Our idea is to obtain optimal number of queues that "best" fits the continuous system.

## 150. List of previous joint publications (if applicable)

[1] Amar Prakash Azad, Sara Alouf, Eitan Altman, Vivek Borkar, and Georgios S. Paschos, "Optimal Control of Sleep Periods for Wireless Terminals". *IEEE JSAC,* Vol. 29 No. 8, Sept 2011.
[2] Chandramani Singh, Eitan Altman Anurag Kumar, and Rajesh Sundaresan, "Spatial SINR Games of Base Station Placement and Mobile Association", accepted to IEEE/ACM Transactions on Networking. 2012.
[3] Ramaiyan Venkatesh, Anurag Kumar and Eitan Altman, "Optimal Hop Distance and Power Control for a Single Cell, Dense, Ad Hoc Wireless Network", ACM library *IEEE Transactions on Mobile Computing,* Volume 11, Issue 11, pp 1601 - 1612, 2012.
[4] Veeraruna Kavitha, Eitan Altman, Rachid El-Azouzi and Rajesh Sundaresan Opportunistic Scheduling I n Cellular Systems in the Presence of Noncooperative Mobiles. IEEE Transactions on Information Theory 58(3): 1757-1773 (2012).
[5] Veeraruna Kavitha, Sreenath Ramanath, and Eitan Altman, *Analysis of small cell networks with randomly wandering users.* INRIA HAL-00660647, *Proc. WiOpt 2012* (Paderborn, Germany, May 14-18, page 60-67, 2012).

## 160. Suggested referees for evaluation of the project (please suggest not more than five Indian and five French referees with their addresses including e-mails. *You may also indicate name(s) of scientists to whom the proposal should not be sent, in your opinion, for reasons of conflict of interest.*

Srikrishna Bhashyam (skrishna@ee.iitm.ac.in)
Joy Kuri (kuri@cedt.iisc.ernet.in)
Abhay Karandikar (karandi@ee.iitb.ac.in)
Swades De (swadesd@ee.iitd.ac.in)
Sanjay Kumar Bose (skbose@iitg.ernet.in)

Merouane Debbah (merouane.debbah@supelec.fr)
Yezekael Hayel (yezekael.hayel@univ-avignon.fr)
Samson Lasaulce (Samson.lasaulce@lss.supelec.fr)
Tijani Chahed (tijani.chahed@it-sudparis.eu)
Jocelyne Elias (jocelyne.elias@gmail.com)

# PART II – BUDGET ESTIMATES*

**The budget estimates for the 2nd and 3rd year can be indicative. There will be flexibility provided to modify the 2nd / 3rd year budget estimates towards the end of the 1st /2nd year respectively based on the actual requirements and expenses incurred in the current year.**

**210. International Travel (no costs to be indicated. IFCAM will calculate the costs associated with each trip based on its own norms)**

**<u>India to France</u>**

211. Proposed number of visits of Indian scientists/students to France

First year : 4
Second year: 3
Third year : 3

212. Duration* of stay during each visit of Indian scientists/students to France (list each visit separately)

15 days per visit for each scientist / student

213. Activities proposed to be performed during each visit

Collaborative research related to the specified objectives.

**<u>France to India</u>**

214. Proposed number of visits of French scientists/students to India

First year: 4
Second year: 3
Third year: 3

215. Duration* of stay during each visit of French scientists/students to India (list each visit separately)

15 days per visit for each scientist / student

216. Activities proposed to be performed during each visit

Eitan Altman will organize a workshop and/or winter school on "Competition in Social Networks" on Dec 2013. Additionally, collaborative research related to specified objectives.

*Minimum duration should be 2 weeks

**Post-doc to be appointed in the project (this position can be provided only against a designated candidate)**

221. Name: Parmod Kumar

222. Current position: Postdoctoral fellow at INRIA

223. Current address: INRIA Sophia-Antipolis, 2004 Route des Lucioles, Sophia-Antipolis, FRANCE.

224. Biodata of the post-doc with list of publications: See attachment

225. Three reference letters to be provided (can be sent by email to ifcam@math.iisc.ernet.in)

226. Proposed period of the post-doc position: 16 months starting from end of November 2012

227. Scientific programme of the post-doc (1 page maximum)

Title: Estimation and Filtering in Delay Tolerant Ad-Hoc Wireless Networks.

Description: The postdoctoral fellow will be part of the cooperation between Maestro group and colleagues in IISc, Bangalore. The candidate will focus on Delay Tolerant Networks. These are sparse ad-hoc networks that use relaying and mobility in order to transfer delay insensitive data packets. The postdoctoral fellow will focus on optimal estimation and filtering for wireless networks, and their use for controlling these networks. This will include Kalman filter and Wiener filter, where the purpose of filtering is to estimate the fraction of relays that have a given content. Such information will be useful in designing energy efficient routing protocols.

The postdoctoral fellow shall study both the cooperative and the noncooperative cases. In the noncooperative case, he shall consider in particular the cases in which one cannot directly observe the actions of the mobiles (due to the low connectivity). In addition to techniques based on filtering, he shall use techniques from the field of “fishery”. As in our case, one cannot observe directly the actions of fishery ships (to verify if they meet quota constraints on allowed fishing), but instead, one can obtain an estimation of the size of the fish population. Optimal dynamic policies switch between cooperative behavior and a noncooperative punishing phase of a "fishery war" depending on the estimated amount of fish. Other applications of filtering will also be considered in the context of sensor networks.

Background needed: Signal processing, filtering.
During postdoctoral study: Classical filtering and H-infinity based filters (for non-Gaussian noise).

**Expenses of the French Collaborator that will be met by Targeted Funds of the IFCAM Project**
(Some French institutions have provided targeted funds to cover expenses of visiting faculty, post-docs and students under the IFCAM project, details of which can be obtained by the French collaborator from his/her institution. If you propose to use these funds to supplement the grant requested above, please indicate this below)

| Details | 1st Year (Euros) | 2nd Year (Euros) | 3rd Year (Euros) |
|---|---|---|---|
| <Awaited> | <Awaited> | <Awaited> | <Awaited> |
| | | | |

**230.** Total budget to be met by targeted funds for the project duration

**Euros <Awaited>**

## ANNEXURE A: COLLABORATORS

**300. Principal Collaborator from India** (Please attach biodata and list of not more than ***10*** *MOST* relevant publications in the last five years. In particular, include joint publications with the French collaborator(s), if applicable)

301. Name and Designation
Rajesh Sundaresan
Associate Professor

302. Sex — Male [X] Female [ ]

303. Date of Birth

| 1 | 4 | | 0 | 2 | | 1 | 9 | 7 | 3 |
|---|---|---|---|---|---|---|---|---|---|
| (Date) | | | (Month) | | | (Year ) | | | |

304. Name of the Institution

Indian Institute of Science

305. Name and Designation of the Head of the Institution

P. Balaram
Director

306. Address :– Institution

ECE Department
Indian Institute of Science
Bangalore 560012
India

Telephone No. : 91 80 2293 2658

Fax No. : 91 80 2360 0563

e-mail :– rajeshs@ece.iisc.ernet.in

307. Address :– Residential

307 Hoysala Vijay Enclave 2
29/1-2, Kalpana Chawla 60 Feet Road
Bhoopasandra, Bangalore 560094
India

Telephone No. : 91 80 4170 6694

Fax No. : NIL

e-mail:– rajeshs@ece.iisc.ernet.in

Relevant joint publications:

- C.Singh, E.Altman, A.Kumar, R.Sundaresan, "Optimal forwarding in delay tolerant networks with multiple destinations," October 2011, to appear, IEEE Transactions on Networking.
- E.Altman, A.Kumar, C.Singh, and R.Sundaresan, "Spatial SINR games of base station placement and mobile association," October 2010, to appear, *IEEE Transactions on Networking*.
- V.Kavitha, E.Altman, R.El-Azouzi, and R.Sundaresan, "Opportunistic scheduling in cellular systems in the presence of noncooperative mobiles," *IEEE Transactions on Information Theory*, vol. 58, no. 3, pp.1757-1773, March 2012
- E.Altman, M.K.Hanawal, and R.Sundaresan, "Nonneutral network and the role of bargaining power in side payments," *Proceedings of the Fourth Workshop on Network Control and Optimization*, NETCOOP 2010, pp. 66-73, Ghent, Belgium, November 2010.
- V.Kavitha, E.Altman, R.El-Azouzi, and R.Sundaresan, "Fair scheduling in cellular systems in the presence of noncooperative mobiles," *Proceedings of the IEEE INFOCOM 2010*, San Diego, USA, March 2010.

**350. Principal Collaborator from France** (Please attach biodata and list of not more than ***10*** *MOST* relevant publications in the last five years. In particular, include joint publications with the Indian collaborator(s), if applicable)

351. Name and Designation

Dr. Eitan Altman

352. Sex — Male [X] Female [ ]

353. Date of Birth

| (Date) | (Month) | (Year) |
|---|---|---|
| 0 9 | 0 1 | 1 9 5 9 |

354. Name of the Institution

INRIA, Sophia-Antipolis

355. Name and Designation of the Head of the Institution

Gerard Giraudon
Head, INRIA Sophia-Antipolis Mediterranee Research Centre

356. Address :– Institution

INRIA Sophia Antipolis – Projet MAESTRO
2004 Route des Lucioles
B.P. 93
06902 Sophia Antipolis Cedex, France

Telephone No. : +33 4 92 38 77 86

Fax No. : +33 4 92 38 78 58

e-mail :– eitan.altman@inria.fr

357. Address :– Residential

335 Chemin des Combes
84140 Montfavet
France

Telephone No. : +33 4 90 31 19 60

Fax No. : ------

e-mail:– eitan.altman@inria.fr

**400. List of Joint Collaborator(s) with Institutional Affiliation:**

INDIA

| | |
|---|---|
| 1. Rajesh Sundaresan | ECE Department, Indian Institute of Science |
| 2. Anurag Kumar | ECE Department, Indian Institute of Science |
| 3. A. Chockalingam | ECE Department, Indian Institute of Science |
| 4. V.S. Borkar | EE Department, Indian Institute of Technology Bombay |
| 5. D. Manjunath | EE Department, Indian Institute of Technology Bombay |
| 6. Veeraruna Kavitha | IEOR Department, Indian Institute of Technology Bombay |

FRANCE

| | |
|---|---|
| 7. Eitan Altman | INRIA, Sophia-Antipolis |
| 8. Balakrishna Prabhu | LAAS, CNRS, Toulouse |
| 9. Charles Bordenave | CNRS, University of Toulouse |
| 10. Marc Lelarge | INRIA Rocquencourt |
| 11. Konstantin Avrachenkov | INRIA, Sophia-Antipolis |

**Note: Please give this certificate on letterhead** **Annexure–B**

**Certificates from the Heads of the Institutions of the Principal Collaborators from India and France**

In order to result in effective, long lasting interactions between scientists of the two countries, it is desired that collaborative programmes supported by IFCAM should correspond to scientific interests of all collaborating laboratories, and not only to those of isolated investigators from these laboratories. For this reason, heads of collaborating laboratories are requested to commit themselves, by verifying that the proposed programme corresponds effectively to a major interest of the group they are responsible for, and by indicating the amount of resources (in terms of recurring expenses, equipment and manpower) allocated to the project from their own budget.

**Project Title:**

(1) Certified that this institution agrees to the participation of________________________(Name) ______________________________________________________(Designation) in this Institution as Principal Collaborator for the above project which is being submitted for support to the Indo–French Centre for Applied Mathematics.

(2) Certified that the infrastructural facilities related to the project activity available in this institution including equipment, manpower and other facilities, and all necessary administrative support will be extended for the project.

(3) This institution assumes to undertake the financial and other responsibilities of the part of the project work which will be conducted in this country.

Date:

Name & Signature
of the Head of the
Institution

Place:

Seal