*Please refer to Associate Teams call for projects: http://en.inria.fr/research/international-mobility/associate-teams/call-for-projects*

***Submit your proposal online before 2011 September 30th on https://international-programs.inria.fr***

**Name of the project: GAME S, OPTIMIZATION AND ANALYSIS OF NETWORKS: THEORY AND APPLICATIONS (GANESH)**

## A. DETAILED PROJECT DESCRIPTION

**A1 Description of the research project** - *2 pages maximum*.

- *Describe the scientific objectives of the project and the method used*
- *Describe how, what and to what extent you intend to advance this research*

***1. Solve some fundamental open problems in networking games***

Two main objectives within this category are

i. **Topological Conditions for Uniqueness of Equilibria in Routing Games**: Come up with a satisfactory theory for uniqueness of equilibria. We have a major contribution already in identifying cost functions for which the equilibrium is unique for splittable routing games with atomic (finite number of) players with arbitrary topology. The open question is to obtain for the same type of problems topological conditions that are necessary and sufficient for uniqueness for any convex increasing link cost functions. So far, the only known results for this have been in the framework in which all players have the same source and the same destination nodes. We intend to extend it to problems where sources and destinations may vary from one player to another.

ii. **Convergence of equilibria in population games:** Find conditions for equilibria in infinite player games to be good approximations of equilibria in games with a finite (but large) number of players.

***2. Modeling distributed decision making in networks***

1 Identify applications in telecommunication networks in which (i) game theory models well pertinent decision-making issues and (ii) team theory has this role.
2 Revisit the utility functions that are used to model optimization and games arising in networks. In particular, check what previously used utility functions are realistic and what are justified by mathematical convenience. Study the impact on the utility of the users by computing equilibria using utilities that deviate from the real utilities.
3 Study the impact of the layered structure of network protocols on the utility of users.
4 Obtain more details on utilities of decision-makers through questionnaires and experimentation.

***3. Network Economic problems and Network Neutrality***

Network Neutrality has been a paradigm for designing networks and providing services over them in a way that does not discriminate among packets: all packets are treated equally, irrespective of their source, destination, content, protocol they use, etc. It has been adopted as part of the legislation for deployment of services over networks in various countries. Two main issues in the debate on neutrality have been whether to allow Internet service providers (ISPs) to impose pricing on content providers (CPs) and whether to allow a service provider to have exclusive agreement with a content provider. We shall use game theory to analyze these questions in the presence of several ISPs and CPs (each representing a player). Among the central novelty in our work are the following: (1) To introduce new indicators and measures for analyzing the impact of collusion. We shall study the impact of collusion both on society, as well as on the colluding

agents. We shall include also a competition over the offered quality of service. In particular, we shall study the case where different agents may have different available information (on the demand function, on the quality of service etc). (2) We shall study some hierarchical problems in which some agents have partial information. The actions (e.g., pricing) by some agents then serve also as signals which may be used by agents with less information. We shall study these issues using signaling games as well as Bayesian games.

***4. Performance Evaluation of New Internet Services***

We shall study the following new services over the Internet:
- streaming services over the Internet, which will be used for both performance evaluation as well as network dimensioning. Our goal is to model the behavior of applications like You Tube, Daily Motion etc on one hand, and streaming video services for longer video streams, on the other hand.
- epidemic models for the propagation of information in social networks.

***5. Performance Analysis, Design, and Distributed Control of Ad Hoc Wireless Networks***

We expect that in the coming years there will be several major drivers for the design and deployment of multihop ad hoc wireless networks; for example wireless sensor networks, and the emerging area of cyber-physical systems. Along with the increase in the need f

or such networks, there will also be growing expectation from their performance. The hundreds of video cameras that are being installed can only be connected wirelessly, and cyber-physical systems will have control loops running over ad hoc networks. We propose to conduct research on the following topics in this broad area

1. Accurate performance models for multihop wireless networks
2. Design of multihop wireless networks to achieve prescribed QoS objectives
3. Self-organisation of these wireless networks in terms of channel selection, power levels, and medium access control.

**A2 Expected project outcomes and scientific value** - *2 pages maximum*

- *Project's characteristics, advancement beyond the state-of-the-art*
- *General orientation of the project (basic research – applied research with or without the participation of industry)*
- *Project's contribution to fostering young researchers*

## Fundamental Open Problems

Games with a continuum set of atomless (or infinitesimal) players have since long been used to model interactions involving a large number of players in which the action of a single player has a negligible impact on the utilities of other players. In road traffic engineering, this was already formalized by Wardrop **[wardrop]** in 1952 to model the choice of routes of cars where each driver, modeled as an atomless player, minimizes its expected travel delay. In Wardrop´s model, there may be several classes of players, each corresponding to another origin-destination pair. The goal is to determine what fraction of each class of players would use the different possible paths available to that class. The equilibrium is known to be unique in terms of link utilization [**BM**] and behaves as the limit of the equilibrium obtained in a game with finitely many players, as their number tends to infinity **[HM].** It is thanks to this limit that there is a sense to focus on a model with infinite number of players. The limit in **[HM]** was obtained, however, under a very restrictive condition, called the "diagonal strict concavity" property. It was shown in the pioneering work [ORS] that indeed, even in the very simple network of two parallel links, and with two players only, the condition does not hold in general, and in order for it to be valid one needs to restrict to very light traffic conditions.

This is an important limitation that is also related to the question of the uniqueness of the equilibrium, as the conditions for which [HM] showed convergence of the equilibrium are also known to guarantee uniqueness of the equilibrium. The fact that they seldom hold in networks with finite number of players suggests that the equilibrium is not unique and indeed, [ORS] obtain several examples of non-uniqueness of the equilibrium in the case of finite number of players. Since then, uniqueness has been established in that framework either under restrictive conditions on the cost or on the topology. [ORS] obtain uniqueness for the very simple topology of parallel links. Since that paper, there have been extensions to a general class of topologies in which, however, all players have the same source and the same destination nodes. We intend to extend it to problems where sources and destinations may vary from one player to another. We shall characterize the topologies for which uniqueness is obtained without assuming a common source and destination.

**Evolutionary Games** Another class of games that involves a continuum of atomless players is the evolutionary games, in which pairs of players that play a matrix game are selected at random, see [Smith72]. The objective is again to predict the fraction of the population (or of populations, in the case of several classes) that play each possible action at equilibrium. A Wardrop type definition of equilibrium can be used, although there has been a particular interest in a more robust notion of equilibrium strategy, called a Evolutionary Stationary Strategy. Evolutionary games deal also with evolution of competition through the so-called **replicator dynamics.**

The current convergence results of replicator dynamics are restricted to pairwise interactions. This is not natural and does not allow to model well situations of competition that involve many TCP connections. Moreover, in practice the number of connections may be a random variable not known to the players. We shall extend the framework of evolutionary games to a random number of players. We shall further plan to obtain convergence conditions for state-dependent extensions that we have recently introduced.

## Modeling distributed decision making in networks

Till around 1990, game theory had been very marginal within the networking community. In the last twenty years, many game models have appeared. Many situations of distributed decision-

makers in networking have been modeled as games but many are not. Non-cooperative games assume selfish behavior and individual decision taking. We plan to come up with guidelines that clarify when is a team setting and when is a non-cooperative setting more appropriate for modeling distributed decision making. We shall also check, experimentally if needed, whether some intermediate degree of cooperation behavior is common in networking, and if so, how to model it. To the best of our knowledge, there has not been any work in these lines in our community.

## Network Economy

When a group of non-cooperative players can join forces and coordinate their actions so as to maximize the sum of utilities of the members of the group, we call this a collusion. When all players collude, then the globally optimal solution is also an equilibrium. In previous work, authors have investigated the question of whether collusions are good or bad for society. We have recently identified cases when collusions are bad not only for society but also for the players who colluded.
We shall get deeper understanding of this phenomenon and derive conditions for it to occur. We shall come up with new measures of the price of collusions, extending those introduced in [R1,R2].

## Evaluation of new services

In the evaluation of new services, our approach is again characterized by proposing mathematical tools that will enable us to obtain both analytical expressions for performance measures as well as insight on the dependence of the system performance on various parameters. The performance measures include packet loss rates and delays, which have been well studied in queueing theory, but also the starvation probabilities, i.e. the probability that the playout buffer is empty, When starvation occurs, then the application cannot play the information data at the speed at which it should be played. We shall use the probability generating function approach, and then use the obtained generating functions to obtain asymptotics of the performance of the initial system. An alternative path that we shall explore will be the use of the Ballot theory. Both methods had been used before in other problems in networks involving queueing analysis [AAJK,GSC].

## Performance Analysis, Design, and Distributed Control of Ad Hoc Wireless Networks

Multihop ad hoc wireless networks are generally only amenable to approximate analysis. We will aim to develop accurate analyses that will incorporate packet arrival processes, queuing at the nodes, CSMA scheduling, and arbitrary topologies and node dependencies. Insights gained from this analytical modeling will be used to develop principles for the design of ad hoc networks that meet various QoS objectives, including throughput, delay, and energy consumption. Since wireless networks may need to share spectrum, and have to operate in a highly time varying competitive environment, we will explore distributed algorithms that will permit the networks to continue to provide quality of service under such conditions.

## References:

**[R1]** Ara Hayrapetyan, Éva Tardos and Tom Wexler: Effect of Collusion in Congestion Games. Proceedings of the ACM Symposium on the Theory of Computing (STOC), 2006
**[AAJK]** O. Ait Hellal, E. Altman, A. Jean-Marie and I.A. Kurkova, ``On loss probabilities in presence of redundant packets and several traffic sources", Performance Evaluation, pp. 486-518, Vol 36-37, 1999.
**[R2]** Chien-Chung Huang: Collusion in Atomic Splittable Routing Games. ICALP (2) 2011: 564-575
**[GSC]** O. Gurewitz, M. Sidi, I. Cidon, ``The Ballot Theorem Strikes Again: Packet Loss Process Distribution ", IEEE Trans. Info. Theory, Vol.46, No.7, 2000

**[HM]** A. Haurie and P. Marcotte, "On the relationship between Nash-Cournot and Wardrop equilibria," Networks, vol. 15, pp. 295–308, 1985.
**[ORS]** A. Orda, R. Rom, and N. Shimkin, "Competitive routing in multi-user communication networks," IEEE/ACM Transactions on Networking, vol. 1, no. 5, pp. 510–520, 1993.
**[BM]** M. Beckmann, C. B. McGuire, and C. B. Winsten, Studies in the Economics of Transportation. New Haven: Yale Univ. Press, 1956.
**[Wardrop]** Wardrop, J. G. (1952) Some Theoretical Aspects of Road Traffic Research. Proceedings of the Institute of Civil Engineers, Part II, 325-378.
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Young Researchers: see next paragraph

## A3 Presentation of each organization and lead researcher credentials – *2 pages maximum*

Brief introduction of the two partner institutions / teams

In red: young researchers (40 years or less)

Indian Team: Includes IISc Bangalore (Prof Anurag Kumar, Prof Vinod Sharma, Dr A Chockalingam, Dr Rajesh Sundaresan), IIT Mumbai (Prof D. Manjunath, Prof V Borkar, Prof Prasanna Chaporkar) and IIT Madras (Dr Venkatesh**).**

Indian students that will participate as part as the French team: Manoj Panda (postdoc at Maestro, did his PhD with Prof Kumar), Mr Manjesh Kummar (Did his Mastrers with Rajesh Sundaresan of IISc). Other participating students: Tejas Bodas (PhD student with Prof Manjunath)

French Team: Includes Eitan Altman and Konstantin Avrachenkov from Maestro group. Eitan is hosted at the networking group of LIA in Avignon University who will participate in the associate team program as part as the French group. (Their eligibility follows a convention with INRIA signed on 2010). (Participants: R El-Azouzi, Y. Hayel and T. Jimenez)

Background of the Principal Investigators on both sides

**Anurag Kumar** obtained his B.Tech. degree from the Indian Institute of Technology at Kanpur (where he was awarded the President's Gold Medal) and the PhD degree from Cornell University, both in Electrical Engineering. He was then with Bell Laboratories, in New Jersey, for over 6 years. Since 1988 he has been with the Indian Institute of Science (IISc), Bangalore, in the Dept. of Electrical Communication Engineering, where he is now a Professor, and is also the Chair of the Electrical Sciences Division. From 1988 to 2003 he was the Coordinator at IISc of the Education and Research Network Project (ERNET), India's first wide-area packet switching network. His area of research is communication networking, specifically, modeling, analysis, control and optimisation problems arising in communication networks and distributed systems. Recently his research has focused primarily on wireless networking. He has been elected Fellow of the IEEE, the Indian National Science Academy (INSA), the Indian National Academy of Engineering (INAE), and the Indian Academy of Science (IASc). He received the IISc Alumni Award for Excellence in Engineering Research for 2008. He has been awarded a DST J.C. Bose National Fellowship for the year 2011-2016. He was an associate editor of IEEE Transactions on Networking, and of IEEE

Communications Surveys and Tutorials. He is a coauthor of the postgraduate text-books ``Communication Networking: An Analytical Approach,'' (published in 2004) and "Wireless Networking" (published in March 2008), both by Kumar, Manjunath and Kuri, and published by Morgan-Kaufman/Elsevier.

**Eitan Altman** received the B.Sc. degree in electrical engineering (1984), the B.A. degree in physics (1984) and the Ph.D. degree in electrical engineering (1990), all from the Technion-Israel Institute, Haifa. In (1990) he further received his B.Mus. degree in music composition in Tel-Aviv university. Since 1990, Dr. Altman has been a researcher at INRIA (National research institute in computer science and control) in Sophia-Antipolis, France. He has been in the editorial boards of several scientific journals: Wireless Networks (WINET), Computer Networks (COMNET), Computer Communications (Comcom), J. Discrete Event Dynamic Systems (JDEDS), SIAM J. of Control and Optimisation (SICON), Stochastic Models, and Journal of Economy Dynamic and Control (JEDC). He received the best paper award in the Networking 2006, in Globecom 2007 and in IFIP Wireless Days 2009 conferences, and is a coauthor of two papers that have received the best student paper awards (at QoFis 2000 and at Networking 2002). His areas of interest include networking, stochastic control and game theory. More informaion can be found at www-sop.inria.fr/members/Eitan.Altman/ He has been elected Fellow of IEEE

Main publications of the participants related to the broad topic of the proposal (mark clearly the joint publications)

Below are joint publications. Blue indicates Indian researchers thatare part of the proposed GANESH project and Red indicates the French ones.

**Venkatesh Ramaiyan, Eitan Altman**, and **Anurag Kumar**, ``Delay Optimal Scheduling in a Two-Hop Vehicular Relay Network," ACM/Springer Mobile Networks and Applications (MONET) , Special Issue on Advances and Applications in Vehicular Ad Hoc Networks, accepted (online version appeared May 2009)

Srinivas Shakkotai, **Eitan Altman**, Anurag Kumar, "The case for noncooperative multihousing of users to access points in IEEE 802.11 WLANs", *IEEE Journal on Selected Areas in Communications, Special Issue on Noncooperative Behaviour in Networking*, Vol 25 No 6, 1207-1215, Aug 2007

**Anurag Kumar**, **Eitan Altman**, Daniele Miorandi and Munish Goyal, ``New Insights from a Fixed Point Analysis of Single Cell IEEE 802.11 WLANs,'' *IEEE/ACM Transactions on Networking* , Vol 15, Issue 3, pp. 588 - 601, June 2007

**Venkatesh Ramaiyan, Anurag Kumar**, and **Eitan Altman**, ``Fixed Point Analysis of Single Cell IEEE 802.11e WLANs: Uniqueness and Multistability," *IEEE Transactions on Networking*, Vol 16 No 5, pp. 1080--1093, Oct. 2008

A. **Chockalingam**, **E. Altman**, J. V. K. Murthy, and R. Kumar, Cross-layer Design for Optimizing TCP Performance, Proc. IEEE ICC'2005, Seoul, May 2005\,

**V. Sharma**, Dharmendra, K. Prasad., **E. Altman**, "Opportunistic Scheduling of Wireless Links", 20th InternationalTeletraffic Congress (ITC 20), Ottawa, Canada, 17-21 june, 2007.

Vijay Kamble, **Eitan Altman, Rachid El-Azouzi** and **Vinod Sharma**, "A Theoretical Framework for Hierarchical Routing Games", Proceedings of IEEE Infocom, San Diego, USA, March 2010.

Veeraruna Kavitha, **Eitan Altman**, **Rachid El-Azouzi and Rajesh Sundaresan**, "Fair scheduling in cellular systems in the presence of noncooperative mobiles", Proceedings of IEEE Infocom, San Diego, USA, March 2010

Chandramani Singh, **Anurag Kumar, Rajesh Sundaresan** and Eitan Altman,"Optimal forwarding in Delay Tolerant Netwrks with Multiple Destinatins," 9th International Sympopsium on Modeling and Optimization in Mobile (WiOpt), Ad Hoc, and WIreless Networks, May 9-13, Princeton, 2011.

Manjesh Kumar Hanawal, Eitan Altman , Rachid El-Azouzi, Balakrishna Prabu."Spatio-temporal control for Dynamic

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| | Routing Games", GameNets, at Sangahi, China, April 2011. |

| A4 | **History of the collaboration between the teams -** *1 page maximum* |
|---|---|

- *Existing activities correlated with the main objective of the project,*
- *Necessity and significance of this collaboration*
- *Added value of this project for each partner*

**History**
We have started our collaboration around ten years ago when Prof Anurag Kumar came for a Sabbatical year to INRIA. We have been the first research team on Information Technology to get financed by CEFIPRA (which included a 2 years postdoc at INRIA, Arzad Kherani , who had done his PhD under the guidance of Prof Kumar). As an award for excellence we received from CEFIPRA a one year prolongation. We now are at the mid-term of a second CEFIPRA project. We have had also a three years Association Team grant from INRIA, see Dawn at http://www-sop.inria.fr/maestro/DAWN/home.html.

**Existing activities.**
We have a joint CEFIPRA project that finances travel between the teams and had financed 2 years of postdoc (who had graduated at IISc) with the French group. We have several PhD students who did their Masters at IISc (Manjesh Kumar and Sreenath Ramanath) at INRIA, and an important part of our collaboration is done with these students. In addition, we have been notified of the acceptance of the joint Lab in applied mathematics in Bangalore where both IISc and the INRIA group participate (yet the date at which the Lab will be operational is yet unknown).

**Necessity and significance of this collaboration** While the existing funds have been extremely useful for joint travels, CEFIPRA has approved to finance only 4 travels from each side for the duration of 3 years, which means less than one travel a year from INRIA (the CEFIPRA project includes other French teams with whom we have to share the travel funds). In addition, while encouraging travels of students not only from India to France but also from France to India, CEFIPRA has restricted its financial support to French citizens, which is a serious constraint as almost all our students fail to meet this criterion.
There are various areas in which both French and Indian teams specialize (performance evaluation, stochastic modeling, Controlled Markov chains) but the strength of the proposal is in the complementarity between the two teams which brings an added value to the cooperation: the Indian side is specialized in Information Theory, in censor networks and in experimental validation, while the French side is specialized in Game Theory and in branching processes and in

complex networks (tools from epidemics).

The current proposal differs significantly from the previous ones in (i) it focuses on designing fundamental tools for the design of networks (the previous cooperation was more application oriented) (ii) Applications are new, (e.g., network economy)
(iii) It has new Indian partners: IIT Mumbai and IIT Delhi, and new members from IISc, and new French members.

**Added value**. The main added value is in the complementarity between the sides described in the previous paragraph. In addition, the French side brings much of its experience obtained from collaborations with service providers (in particular France Telecom) where as the Indian side brings its experience from the own implementations and experiments done by the Indian groups as well as their experience from collaboration with companies in India that specialize in equipment and hardware. The cooperation is also a unique opportunity to attract to INRIA outstanding students from Bangalore.

## A5 Scientific work program

Duration of the project : 3 years

**Work Program**

- *Describe the scientific tasks planned for the duration of the project*
- *Explain how these tasks are distributed among the participating teams*

**Task 1**: **Open problems**.
Task 1.1 will be devoted to uniqueness in routing games and be carried by E Altman and T Jimenez of the French group. Will be carried on during the first 18 months.
Task 1.2: The convergence issues to equilibria with a continuum of players. Will be carried out by R. El-Azouzi and K. Avratchenkov from the French team and V Borkar from the Indian team.
Will be carried out during the last 18 months.

**Task 2: Modeling distributed decision making:**
Will be carried out by the French group and IIT Madras. The work will go on all along the three years. The experimental part and the work on utilities will be performed in the first year and will serve as input to task 5.

**Task 3: Economy of networks:** will be investigated by the French team as w ell as by Sundaresan from IISc during years 1 and 2.

**Task 4**: Evaluation of new services: will be handled by the French team together with Prof Anurag Kumar and Vinod Sharma from IISc.

**Task 5**: **Integration: Scheduling for Cellular Wireless Networks**
a) Study the impact of channel statistics and user utility on the dynamic performance of a wireless schedulers.
b) Develop a general scheduling strategy for arbitrary quality of service.
c) Validate definitions of quality of service and notions of fairness for different traffic models.

Parts a and will complement the theoretical work on the sensitivity of equilibria to the utilities. Part c will complement the Task on performance measures of new services.

The task will go on all along the project and will involve theh whole French group as well as IIT Madras and IISc

**Task 6: Integration: Wireless Ad-hoc network.** As we get understanding on what the utility functions really are and who is actually plaing the game, we shall apply these to Ad hoc networks. This again will help validate the first part.

Outline how the partners will coordinate their joint activities and the specific part of each organization (e.g. workshops, website, videoconferencing, etc.)

A Web site will be maintained by the French coordinator. Most of the members of the Indian team and of the French team attend the conferences WiOpt and Infocom. We shall thus try to organize meetings of Ganseh just before or just after these conferences. We have very positive experience with videoconfs with skype

| A6 | Exchanges schedule for Year 1 |
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Exchanges scheduled from France to the partner country (researchers' name, including students, and expected duration of stays)

Manjesh Kumar (PhD student ) and Manoj Panda (postdoc at Maestro): travel to IISc during the whole February, 2012 for both.

E. Altman et T Jimenez: une mission d'une semaine a IISc et une semaine a IIT Bombay, Novembre 2012

Rachid El-Azouzi (Univ Avignon): travel to IISc during February 20th – March 3, 2012
This travel will be payed by Cefipra

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| | Exchanges scheduled from the partner country to France (researchers' name, including students, and expected duration of stays)<br><br>P Chaprokar (IIT Bombay) and<br>Rajesh Sundaresan (IISc): travel to INRIA during 1-13 May, 2012<br>(prior to WiOpt conference).<br><br>Venkatesh (IIT Madras): travel on sept 2012 for three weeks.<br><br>K P Naveen (IIsc, PhD student of Prof Kumar); will come during the whole of October 2012.<br>Tejas Bodas (PhD student with Prof Manunath) will come for 4 weeks after netcoop conferencen (November 2012)<br><br>One of the visits from IISc will be covered by CEFIPRA.<br><br>We also include travel money for financing 2 interns in France |

| **A7** | **Additional information** |
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## B. PROJECT FUNDING

**B1 Expected expenditures for Year 1**

| | | Senior researcher | Postdoctoral fellow | PhD student | Intern | Other | Total |
|---|---|---|---|---|---|---|---|
| Visits of INRIA researchers to partners | Number of persons | 3 | 1 | 1 | 0 | 0 | 6 |
| | Estimated cost (€) | **7200** | **3000** | **3000** | **0** | **0** | **13200** |
| Invitation of partner researchers to INRIA | Number of persons | 3 | 1 | 2 | 2 | 0 | 8 |
| | Estimated cost (€) | **6000** | **0** | **6000** | **2400** | **0** | **14400** |

**B2 Budget proposal for Year 1**

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|---|---|
| **Financial support request to INRIA* under the Associate Team program**<br>** The maximum amount awarded by INRIA is 20000 € per year* | €20000 |

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|---|---|
| **Expected financial and/or material contribution from the international partner to the project**<br>➢ *Please detail: …* | € |
| **Other resources benefiting to the project**<br>➢ *Please detail (contract, grant, etc.): … CEFIPRA* | € 7600 |
| **Total** | € 27600 |