Activity Report 2011

Project-Team RAP

Networks, Algorithms and Probabilities

RESEARCH CENTER
Paris - Rocquencourt

THEME
Networks and Telecommunications

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Project-Team RAP

Keywords: Markovian Model, Stochastic Algorithms, Distributed Algorithms, Optical Networks

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2. Overall Objectives

2.1. Overall Objectives

The research team RAP (Networks, Algorithms and Communication Networks) was created in 2004 on the basis of a long standing collaboration between engineers at Orange Labsin Lannion and researchers from INRIA Paris — Rocquencourt. The initial objective was to formalize and expand this fruitful collaboration.

At France-Telecom R&D in Lannion, the members of the team are experts in the analytical modeling of communication networks as well as on some of the operational aspects of network management concerning traffic measurements on ADSL networks, for example.

At INRIA Paris — Rocquencourt, the members of RAP have a recognized expertise in modeling methodologies applied to stochastic models of communication networks.

RAP also has the objective of developing new fundamental tools to investigate *probabilistic* models of complex communication networks. We believe that mathematical models of complex communication networks require a deep understanding of general results on stochastic processes. The two fundamental domains targeted are:

1. Design and analysis of algorithms for communication networks.
2. Analysis of scaling methods for Markov processes: fluid limits and functional limit theorems.

From the very beginning, it has been decided that RAP would focus on a number of particular issues over a period of three or four years. The general goal of the collaboration with Orange Labs is to develop, analyze and optimize algorithms for communication networks. Two domains are currently investigated in the framework of this collaboration:

1. Design of algorithms to allocate bandwidth in optical networks.
2. Content Centric Networks.

3. Scientific Foundations

3.1. Design and Analysis of Algorithms

The general goal of the research in this domain is of designing algorithms to analyze and control the traffic of communication networks. The team is currently involved in the design of algorithms to allocate bandwidth in optical networks and also to allocate resources in content-centric networks. See the corresponding sections below.

3.2. Scaling of Markov Processes

The growing complexity of communication networks makes it more difficult to apply classical mathematical methods. For a one/two-dimensional Markov process describing the evolution of some network, it is sometimes possible to write down the equilibrium equations and to solve them. The key idea to overcome these difficulties is to consider the system in limit regimes. This list of possible renormalization procedures is, of course, not exhaustive. The advantages of these methods lie in their flexibility to various situations and to the interesting theoretical problems they raised.

A fluid limit scaling is a particularly important means to scale a Markov process. It is related to the first order behavior of the process and, roughly speaking, amounts to a functional law of large numbers for the system considered.

A fluid limit keeps the main characteristics of the initial stochastic process while some second order stochastic fluctuations disappear. In "good" cases, a fluid limit is a deterministic function, obtained as the solution of some ordinary differential equation. As can be expected, the general situation is somewhat more complicated. These ideas of rescaling stochastic processes have emerged recently in the analysis of stochastic networks, to study their ergodicity properties in particular.

4. New Results

4.1. Algorithms: Bandwidth Allocation in Optical Networks

Participants: Christine Fricker, Philippe Robert, James Roberts.

The development of dynamic optical switching is widely recognized as an essential requirement to meet anticipated growth in Internet traffic. Since September 2009, RAP has begun an investigation into the traffic management and performance evaluation issues that are particular to this technology. A first analysis of passive optical networks used for high speed Internet access has led to the proposal of an original dynamic bandwidth allocation algorithm and to an evaluation of its traffic capacity. Our activity on optical networking is carried out in collaboration with Orange Labs with whom we have had a research contract and are currently finalizing a new one. We have also established contacts with Alcatel-Lucent Bell Labs and had fruitful exchanges with Iraj Saniee and his team on their proposed time-domain wavelength interleaved networking architecture (TWIN).

We have also analyzed the traffic capacity of wavelength division multiplexing (WDM), passive optical networks (PONs) where user stations (optical network units) are equipped with tunable transmitters. For these systems users can use any of the multiple wavelengths to transmit their data but only within the limit determined by the number of transmitters they possess. A mean field approximation is investigated to estimate the capacity of a limited-gated multiserver polling system with a limit on the number of servers a given station can use simultaneously. The approximation provides an expression for the stability limit under very general assumptions about the traffic process and system configuration.

More generally, motivated by these next generation passive optical networks, a multi-server polling system has been studied where the number of servers that can attend to a queue simultaneously is limited. The stability condition is investigated for this model under quite general assumptions. The result is proved for unlimited service policies. The paper [1] presents a conjecture for the case of limited service policies and general service limits. A simulation study shows that the stability conditions may hold.

In 2011, we have worked on bandwidth allocation in meshed networks. A first study applies the TWIN architecture for a metropolitan area network but with an original medium access control (MAC) algorithm. This algorithm is inspired by our prior work on access networks and ensures an efficient and fair allocation of bandwidth to flows between network nodes. The paper [9] describes this network architecture and presents a performance evaluation using analytical models backed up by simulations.

The TWIN architecture is not extensible to a wide area for reasons of scalability and the excessive signalling delay between geographically distant nodes. We have therefore invented a new notion of a multipoint-to-multipoint lightpath that avoids these problems. A patent application relating to this invention has been submitted. This patent is owned by Orange following the terms of our contract with them. The second patent (that simply perfects the first invention) is jointly owned since the research was performed after the end of this contract. The submitted paper [13] describes the invention and its evaluation. A major advantage demonstrated in this paper is the energy saving achieved by the use of the proposed optical technology in place of electronic routers.

Ongoing research seeks to apply this type of networking solution to data centres, on one hand, and to geographically spread tier 1 Internet carrier networks, on the other. This work is performed in collaboration with Orange Labs and will be covered by a contract that is close to being finalized. We have also participated in the preparation of a European CELTIC project proposal that includes a work package dedicated to the development and experimentation of the network proposed in [13].

4.2. Algorithms: Content-Centric Networking

Participants: Mathieu Feuillet, Christine Fricker, Philippe Robert, James Roberts, Nada Sbihi.

RAP is participating in an ANR project named CONNECT which will contribute to the definition and evaluation of a new paradigm for the future Internet: a content-centric network (CCN) where, rather than interconnecting remote hosts like IP, the network directly manages the information objects that users publish, retrieve and exchange. CCN has been proposed by Van Jacobson and colleagues at the Palo Alto Research Center (PARC). In CCN, content is divided into packet-size chunks identified by a unique name with a particular hierarchical structure. The name and content can be cryptographically encoded and signed, providing a range of security levels. Packets in CCN carry names rather than addresses and this has a fundamental impact on the way the network works. Security concerns are addressed at the content level, relaxing requirements on hosts and the network. Users no longer need a universally known address, greatly facilitating management of mobility and intermittent connectivity. Content is supplied under receiver control, limiting scope for denial of service attacks and similar abuse. Since chunks are self-certifying, they can be freely replicated, facilitating caching and bringing significant bandwidth economies. CCN applies to both stored content and to content that is dynamically generated, as in a telephone conversation, for example. RAP is contributing to the design of CCN in two main areas:

- the design and evaluation of traffic controls recognizing that TCP is no longer applicable and queue management will require new, name-based criteria to ensure fairness and to realize service differentiation;
- the design and evaluation of replication and caching strategies that realize an optimal trade-off of expensive bandwidth for cheap memory.

The team will also contribute to the development of efficient forwarding strategies and investigate economic arguments that make CCN a viable replacement for IP.

The ANR project began in January 2011 and several task meetings have taken place. We have also held meetings with PARC establishing close cooperation with them and with some participants in the NSF project "Named Data Networking". We also participated in the CCN Community meeting in Palo Alto where we presented our work on traffic control. A paper describing the proposed flow-aware approach and results of a performance evaluation has been accepted for the conference Infocom 2012 [15].

Work on the performance of caching in CCN is ongoing. We have investigated popularity distributions for various types of content and evaluated their impact on the memory bandwidth tradeoff to be realized by CCN.

4.3. Algorithms: Channel Access algorithms in wireless networks

Participants: Mathieu Feuillet, Philippe Robert.

This is a collaboration with Thomas Bonald (Telecom ParisTech) and Alexandre Proutière (Microsoft Research). In wireless networks, to share available bandwidth between users is necessary. The bandwidth can be divided in several channels (frequency division) or the users can share the whole bandwidth by transmitting in different time slots (time division). We are studying different algorithms that allow users of a wireless network to access the channel. Those algorithms must avoid collisions and use the available bandwidth in the most efficient way. More and more wireless networks are decentralized and those algorithms must be distributed. Moreover, in order to use bandwidth in an efficient way, it is necessary to take the network topology into account. Recent studies have shown that it is possible to use the available bandwidth in a distributed and efficient way without message passing.

We studied a simplified version of the 802.11 channel access algorithm: CSMA/CA (Carrier Sense Multiple Access With Collision Avoidance). We proved that this algorithm does not use the bandwidth in the most efficient way and we proposed in 2010 a modification of this algorithm that is efficient. This result has been extended to multi-channels networks in [8] and its extended version [12].

4.4. Scaling Methods: Fluid limits in wireless networks

Participant: Philippe Robert.

This is a collaboration with Amandine Veber (CMAP, École Polytechnique). The goal is to investigate the stability properties of wireless networks when the bandwidth allocated to a node is proportional to a function of its backlog. This is, in some sense, a generalization of processor-sharing policies. We have investigated the fluid limits of simple examples of star topologies when the function used is $\log$. We have shown that, under this scaling, some new phenomenon occurs, namely that a node may stabilize for some time at some very high level while the number of jobs of other nodes decreases at some fixed rate or remains finite, i.e. lives in the neighborhood of 0. An averaging phenomenon plays an important role for the return to equilibrium.

4.5. Algorithms: Distributed Hash Table

Participants: Mathieu Feuillet, Philippe Robert.

The Distributed Hash Table (DHTs) consists of a large set of nodes connected through the Internet. Each file contained in the DHT is stored in a small subset of these nodes. Each node breaks down periodically and it is necessary to have back-up mechanisms in order to avoid data loss. A trade-off is necessary between the bandwidth and the memory used for this back-up mechanism and the data loss rate. Back-up mechanisms already exist and have been studied thanks to simulation. To our knowledge, no theoretical study exists on this topic. We modeled this problem thanks to standard queues in order to understand the behavior of a single file and the global dynamic of the system. With a very simple centralized model, we have been able to emphasise a trade-off between capacity and life-time with respect to the duplication rate. From a mathematical point of view, we have been able to study different time scales of the system with an averaging phenomenon. An article is in preparation on this subject. A more sophisticated distributed model with mean field techniques is under investigation.

On the side of this project, we notably studied the distribution of hitting times of the classical Ehrenfest and Engset models by using martingale techniques, furthermore their asymptotic behavior has been analyzed when the size of the system increases to infinity [5].

4.6. Stochastic Modeling of Biological Networks

Participants: Emanuele Leoncini, Philippe Robert.

This is a collaboration with Vincent Fromion from INRA Jouy en Josas, which started on October 2010.

The goal is to propose a mathematical model of the production of proteins in prokaryotes. Proteins are biochemical compounds that play a key role in almost all the cell functions and are crucial for cell survival and for life in general. In bacteria the protein production system has to be capable to produce abut 2500 different types of proteins in different proportions (from few dozens for the replication machinery to more than 100000 for certain key metabolic enzymes). Bacteria uses more than the 85% of their resources to the protein production, making it the most relevant process in these organisms. Moreover this production system must meet two opposing problems: on one side it must provide the minimal proteins quantities in order to ensure the smooth-running of the cell, on the other side it can not choose a "overproduction policy" for all the proteins, since this would impact the global performance of the system and of the bacterium itself.

Gene expression is intrinsically a stochastic process: gene activation/deactivation occurs by means the encounter of polymerase/repressor with the specific gene, moreover many molecules that take part in the protein production act at extremely low concentrations.

We have restated mathematically the classical model using Poisson point processes. This representation, well-known in the field of queueing networks but, as far as we know, new in the gene expression modeling, allowed us to weaken few hypothesis of the existing models, in particular the Poisson hypothesis, which is well-suited in some cases, but that, in some situations, is far from the biological reality as we consider for instance the protein assemblage.

The theoretical environment of Poisson point processes has lead us to propose a new model of gene expression which captures on one side the main mechanisms of the gene expression and on the other side it tries to consider hypothesis that are more significant from a biological viewpoint. In particular we have modeled: gene activation/deactivation, mRNA production and degradation, ribosome attachment on mRNA, protein production and degradation.

We have shown how the probability distribution of the protein production and the protein lifetime may have a significant impact on the fluctuations of the number of proteins. We have obtained analytic formulas when the duration of protein assemblage and degradation follows a general probability distribution, *i.e.* without the Poisson hypothesis. We have used our model to compare the variances resulting by choosing different hypotheses for the probability distribution of the protein production and degradation, in particular we have hypothesize the protein assembly and degradation to be deterministic. The model has showed how, under the previous hypothesis, the variance on the number of proteins is bigger than the classical model with the Poisson hypothesis.

4.7. Stochastic networks: large bike sharing systems

Participant: Christine Fricker.

This is a collaboration with Nicolas Gast (EPFL) started in December 2010. Bike sharing systems were launched by numerous cities as a serious alternative in urban transportation, for example Velib (20 000 bikes, 1 500 stations). One of the major issues is the availability of the resources: bikes or free slots to return the bikes. These systems have become a hot topic in Operation Research but there are few studies on these stochastic networks. To our knowledge, no theoretical study of such bike sharing systems exists taking into account the limited capacity of the stations.

We modeled this system in a symmetrical case. Mean field limit theorems give the dynamic of a large system and the stationary behavior of a single station. Analytical results are obtained and convergence proved in the standard model via Lyapunov functions. It allows to find the best ratio of bikes per station and to measure the improvement of incentive mechanisms, as choosing among two stations for example, or redistribution of bikes by trucks. It is under investigation. Further results deal with heterogeneous systems. Our goal is to propose via a theoretical study and tests simple algorithms to improve the system behavior.

4.8. Stochastic networks: heterogeneity

Participants: Christine Fricker, Hanène Mohamed.

Mean field techniques applied to non-symmetrical systems are explored. It appears as a promising way to obtain analytical results on systems with clusters.

4.9. Stochastic Networks: Jackson Networks

Participant: Danielle Tibi.

Lyapunov functions and essential spectral radius of Jackson networks, joint work with I. Ignatiouk-Robert (University of Cergy-Pontoise). A family of explicit multiplicative Lyapunov functions is constructed for any stable Jackson network. Optimizing the multiplicative factor over this family provides an upper bound for the essential spectral radius of the associated Markov process. For some particular classes of Jackson networks, this upper bound coincides with a lower bound derived from large deviations arguments, thus providing the exact value of the essential spectral radius. The main example is given by Jackson networks with routing matrix having a tree structure (in the sense that for any node i, at most one other node can route its customers to i). The result also holds for other types of routing matrices (e.g. completely symmetrical), under some conditions over the different arrival and service rates.

4.10. Scaling Methods: Interaction of TCP Flows

Participant: Philippe Robert.

This is a collaboration with Carl Graham (CMAP, École Polytechnique). Mathematical modeling of data transmission in communication networks has been the subject of intense activity for some time now. For data transmission, the Internet can be described as a very large distributed system with self-adaptive capabilities to the different congestion events that regularly occur at its numerous nodes. The coexistence of numerous connections in a network with a general number of nodes has been analyzed in a previous work through a mean-field limit of a Markovian model describing the interaction of several classes of *permanent connections*. In [6], this line of work has been generalized to the case when connections are not permanent but can be either active (ON) when it is transmitting data along its route, or idle (OFF). This year, the analysis of dynamic arrivals and departures has been investigated. The main technical problem is that mean-field asymptotics are not anymore usable. Instead, fluid limit schemes have to be considered in a quite delicate context, random measures.

5. Contracts and Grants with Industry

5.1. Contracts

- CRE with Orange Labs " Dynamical Optical Networking in the Internet". Contract on bandwidth allocation algorithm in optical networks. Duration 2 years starting from 01/01/12.
- CELTIC-Plus Saser "Safe and Secure European Routing" submitted. RAP participates in the section on optical networks. Participants include Orange labs, Alcaltel-Lucent, Telecom Institute, ENSSAT as well as a number of German laboratories. Duration three years.

- ANR Project "CONNECT: Content-Oriented Networking: a New Experience for Content Transfer". The proposal submitted to the VERSO programme has been accepted. The planned starting date is January 2011 and the project is scheduled to last 2 years. The lead partner is Alcatel-Lucent Bell Labs France and the other partners are RAP, INRIA/PLANETE, Orange LAbs, TelecomParisTech, UPMC.

6. Partnerships and Cooperations

6.1. PhD Grants

PhD grant CJS (Contrat Jeune Scientifique) Frontières du vivant of INRA for Emanuele Leoncini.

6.2. Visiting scientists

RAP team has received the following people:

- Thomas Bonald (Telecom ParisTech, Paris)
- Raluca Indre (Orange Labs)
- Davide Cuda (Orange Labs)
- Jonathan Touboul (INRIA, GANG)
- Amandine Véber (CMAP, École Polytechnique)
- Fabien Mathieu (INRIA BANG)
- Urtzi Ayesta (BCAM, Bilbao, Spain)
- Maaike Verloop (BCAM, Bilbao, Spain)
- Philippe Chassaing (Institut Élie Cartan, Université Henri Poincaré, Nancy)
- Nicolas Gast (EPFL)
- Irina Ignatiouk (Université de Cergy-Pontoise)
- Justin Salez (INRIA, TREC)
- Amar Prakash Azad (UC Santa Cruz, USA)

7. Dissemination

7.1. Leadership within scientific community

Philippe Robert is Associate Editor of the Book Series "Mathématiques et Applications" edited by Springer Verlag and Associate Editor of the journal "Queueing Systems, Theory and Applications". He is member of the scientific council of EURANDOM. He is also associate Professor at the École Polytechnique in the department of applied mathematics where he is in charge of lectures on mathematical modeling of networks. He has been a member of the technical programme committee of the conference ACM Sigmetrics and Technical Program Chair (TPC) of the conference Performance.

James Roberts is a Fellow (membre émérite) of the SEE. In 2011, he has been a member of the technical programme committee of the following conferences: Sigmetrics, Networking, CoNext, Performance, ITC.

7.2. Teaching

Mathieu Feuillet is teaching assistant for the course "Traffic, Queueing and Networks" given by Thomas Bonald at Telecom ParisTech. A book (available in French [11] and English [10]) has been written based on this course.

Christine Fricker was reviewer for the thesis defense of Gonçalo Jacinto's at the University of Lisbon.

Emanuele Leoncini is teaching assistant for the course "Séries et intégrales (étude approfondie)" at University Paris VI.

Philippe Robert gives Master2 lectures "Analyse probabiliste d'algorithmes" in the laboratory of the Probability of the University of Paris VI. He is also giving lectures in the "Programme d'approfondissement de Mathématiques Appliquées et d'Informatique" on Networks and Algorithms at the École Polytechnique. He gave a series of lectures at the University of Casablanca and a conference at the Lycée Rosa Park in Montgeron (91).

James Roberts lectured to third year students at Telecom ParisTech on "Traffic management and the future Internet". He was reviewer for the thesis defense of M. Dirani (Paris VI).

7.3. Conference and workshop committees, invited conferences

Mathieu Feuillet gave a talk at the conference CISS'2011 in Baltimore (March 2011), an invited talk at the workshop YEQT in Eindhoven (October 2011) and a set of two lectures as an invited researcher in Montevideo, Uruguay (December 2011).

Christine Fricker gave an invited talk on 'Performance of passive optical networks' at Lisbon University 11/1-03. She visited Lisbon and Algrave Universities in Portugal (one week). She gave an invited talk on Mean field for large bike sharing systems at Informs Conference on Applied Probability, Stockholm, 11/14-07. Her co-author N. Gast gave an invited talk on their joint work in a sponsored session on operational aspects of bike sharing systems in the INFORMS Annual Meeting at Charlotte, North Carolina, November 13-16, 2011.

Emanuele Leoncini participated at the conferences "European Conference on Mathematical and Theoretical Biology" in Krakow (June 2011) and "INFORMS" in Stockholm (July 2011).

Philippe Robert gave a talk at the University of Marne la Vallée at the PDMP conference and a plenary talk at the conference INFORMS in Stockholm.

James Roberts gave a keynote presentation at the European Teletraffic seminar at Poznan (Feb), an invited talk at the ResCom workshop in Paris (Oct) and an invited talk at the COMET-ENVISION Workshop in London (Nov).

8. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journal

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[4] M. FEUILLET. *On the flow-level stability of data networks without congestion control: the case of linear networks and upstream trees*, in "Queueing Systems, Theory and Applications", 2011, to appear, http://arxiv.org/abs/1006.2313.

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[7] N. LITVAK, P. ROBERT. *A Scaling analysis of a Cat and Mouse Markov chain*, in "Annals of Applied Probability", 2011, To Appear, http://arxiv.org/abs/0905.2259.

International Conferences with Proceedings

[8] T. BONALD, M. FEUILLET. *On Flow-Aware CSMA in Multi-Channel Wireless Networks*, in "CISS", march 2011.

[9] P. ROBERT, J. ROBERTS. *A Flow-aware MAC Protocol for a Passive Optical Metropolitan Area Network*, in "23th ITC Specialist Seminar on Internet Traffic Engineering and Traffic Management", San Francisco, 2011, http://arxiv.org/abs/1102.3538.

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[10] T. BONALD, M. FEUILLET. *Network Performance Analysis*, ISTE/Wiley, july 2011, http://iste.co.uk/index.php?f=x&ACTION=View&id=439.

[11] T. BONALD, M. FEUILLET. *Performances des réseaux et des systèmes informatiques*, Collection Télécoms, Hermes Sciences, april 2011, http://www.lavoisier.fr/livre/notice.asp?id=3LKWX3A36LLOWU.

Other Publications

[12] T. BONALD, M. FEUILLET. *Performance of CSMA in multi-channels wireless networks*, 2011, submitted.

[13] D. CUDA, R.-M. INDRE, E. LE ROUZIC, J. ROBERTS. *Getting routers out of the core: Building an optical wide area network with "multipaths"*, 2011, submitted, http://arxiv.org/abs/1110.1245.

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