INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team rap

Réseaux, Algorithmes et Probabilités

Paris - Rocquencourt

Theme : Networks and Telecommunications

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1. Team

Research Scientists

Christine Fricker [Research Associate (CR) Inria]
Fabrice Guillemin [France Telecom R&D, Lannion]
Stéphanie Moteau [France Telecom R&D, Lannion]
Philippe Robert [Team Leader, Research Director (DR) Inria, HdR]
James Roberts [Research Director (DR) Inria]

Faculty Members

Hanène Mohamed [Université Paris Ouest Nanterre La Défense]
Danielle Tibi [Université Denis Diderot]

PhD Students

Mathieu Feuillet [Détachement du Corps des Mines]
Emanuele Leoncini [INRA-INRIA]
Nada Sbihi [Internship from 04/10 to 08/31. PhD from 09/01]

Visiting Scientist

Nelson Antunes [Visiting Scientist until August 31 2010, University of Algarve]

Administrative Assistant

Virginie Collette [(AI) Inria]

Other

Lin Zhu [Internship INRIA From 04/10 to 08/31]

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 Labs in 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: Nelson Antunes, 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 [10], [11]. Our activity on optical networking is carried out in collaboration with Orange Labs with whom we have a research contract. We have also established contacts with Alcatel Bell Labs and look forward to collaborating with Iraj Saniee and his team on their proposed time-domain wavelength interleaved networking architecture (TWIN).

The study [8] analyzes 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, we consider in [17] a multi-server polling system 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. A conjecture is given for the case of limited service policies and general service limits. A simulation study shows that the stability conditions may hold.

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 is planned to begin in January 2011. Our work has already begun, however, notably in a collaboration with Orange Labs on the definition of flow-based traffic controls. A paper was submitted (but not accepted) to the workshop ReArch (Re-architecting the Internet) associated with CoNext 2010.

4.3. Algorithms: Internet without Congestion Control Algorithms

Participant: Mathieu Feuillet.

It is commonly accepted that the observed robustness of the Internet in the last two decades, despite an exponential growth in traffic, is largely due to the use of congestion control algorithms. Since the introduction of congestion control mechanisms in TCP in the late 1980s, no congestion collapse has been observed. Unfortunately, it is not clear if the IETF will be able to enforce the use of TCP in the future. More and more applications do not comply with the "TCP-friendliness" principle. With the generalization of broadband access through optical fiber (FTTH), the impact of such applications cannot be neglected.

In this project we analyze Internet behavior at flow level in the absence of any control congestion. We assume all sources send at their maximum access rate and recover from packet loss by the use of some source coding or retransmissions independent of the congestion control. The bandwidth allocation is then fully determined by the buffer management policy implemented in routers. We study two possible policies: *Fair Dropping* and *Tail Dropping*. In both cases, we study the efficiency of resource utilization in terms of the maximum load the network can sustain. For *Fair Dropping*, utilization is optimal. This is not the case for *Tail Dropping* although efficiency is shown to be very high in most topologies of practical use. For the latter, the order of magnitude difference between the maximum access rates and link capacity plays a crucial role. The role of the maximum access rates is precisely analyzed in [18].

4.4. Algorithms: Channel Access algorithms in wireless networks

Participants: Mathieu Feuillet, Philippe Robert.

This is a collaboration with Thomas Bonald (Télécom 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 a modification of this algorithm that is efficient [2]. Another family of algorithms has been studied in [15].

4.5. Algorithms: Distributed Hash Tables

Participants: Mathieu Feuillet, Philippe Robert.

The Distributed Hash Tables (DHTs) consist in 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 does exist 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. Different back-up mechanisms are currently under investigation. On the side of this project, we notably studied the distribution of hitting times of the classical Engset model by using martingale techniques, furthermore their asymptotic behavior has been analyzed when the number of nodes in the DHT increases to infinity.

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 in October. The goal is to propose a mathematical model of the production of proteins in prokaryotic cells. Production of proteins consumes about 70% of the energy of the cell, it is, up to now, not known how the cell can manage to make about 2000 different proteins in different proportions without producing too much or too little. The key mathematical characteristic to investigate are the variances of the concentration of proteins.

4.7. Stochastic networks: vehicle rental networks

Participant: Christine Fricker.

This is a collaboration with Frédéric Meunier (LVMT, ENPC). A vehicle rental network where it is always possible to park the vehicle after using it has been modeled in the literature as a closed network where the vehicles represent the customers. We revisit the existing results, especially asymptotics when the fleet size gets large, with a fixed number of stations. The results prove that the capacities of some stations are crucial. To introduce them in the model, we study a a mean field limit for the symmetrical case of the most natural policy: A user, who finds no idle place to put his vehicle when he arrives to a station, tries to park it at another station at random. Using standard arguments, it is proved that the empirical measure of the model converges to a dynamical system as the system gets large. The queueing interpretation of the equilibrium point, which exists, gives the proof of its uniqueness. A different model where the user always returns the vehicle in a non-saturated station should be compared to the previous one. The aim is to examine the impact of the parking policy. A framework with different clusters is under investigation.

4.8. 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 Jackson networks corresponding to some particular class of routing matrices, this bound actually coincides with the exact value of the essential spectral radius, as can be derived from large deviations arguments.

4.9. 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 [19], 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). A Markovian model is provided by the states (OFF, or ON with some transmission rate) of the connections. Each connection is assumed to have a self-adaptive behavior in that its transmission rate along its route depends on the level of congestion of the nodes of the route. The number of connections in each class being potentially huge, a mean-field limit result is proved with an appropriate scaling so as to reduce the dimensionality. In the limit, the evolution of the states of the connections can be represented by a non-linear system of stochastic differential equations, of dimension the number of classes. Additionally, it is shown that the corresponding stationary distribution can be expressed by the solution of a fixed-point equation of finite dimension involving the resolvent of a Markov process describing the evolution of an isolated connection.

5. Contracts and Grants with Industry

5.1. Contracts

- CRE with Orange Labs “Algorithmes d’allocation de ressources dans les réseaux optiques”. Contract on bandwidth allocation algorithm in optical networks. Two years starting from 2009.
- CRE with Orange Labs “Flow-aware resource management in a content-centric network”. Contract for 9 months from March 2010.
- 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. Other Grants and Activities

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:

- Nidhi Hegde (Orange Labs) 01/08;
- Pascal Moyal (Université de Technologie de Compiègne) 01/18;
- Alberto Blanc (INRIA Sophia-Antipolis, MAESTRO) 01/27;
- Fabien Mathieu (Orange Labs) 01/29;
- Nelly Litvak (University of Twente) (02/15-02/19);
- Stratis Ioannidis (Technicolor Corporate Research, Paris Laboratory) 04/29;
- Thomas Bonald (Telecom ParisTech) 04/09;
- Danielle Tibi (Paris 7) 04/29;
- T. Kamei and M. Suzuku (Nomura Research Institute, Japan) 06/30;
- Raluca-Marie Indres (Orange Labs) 11/04;
- Nikita Vvedenskaya (IITP, Moscow) 11/16;
- Tembine Hamidou (Supelec, France) 11/16;
- Amandine Veber (École polytechnique, CMAP) 11/26;
- Florence Bénézit (INRIA Paris-Rocquencourt, TREC) 12/16;
- Nicolas Gast (EPFL) 12/15-12/17;

7. Dissemination

7.1. Leadership within scientific community

Mathieu Feuillet was awarded a prize in march 2010 by the Fondation Télécom for his internship at Microsoft Research and Orange Labs in 2008-2009.

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 was in the evaluation committee of the ANR "Programme Blanc" for mathematics.

James Roberts is a Fellow (membre émérite) of the SEE. He received a "Lifetime achievement award" in September from the ITC Advisory Council.

7.2. Teaching

Mathieu Feuillet is teaching assistant for the course "Traffic, Queueing and Networks" given by Thomas Bonald at Télécom ParisTech.

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 has been reviewer of the R. Sahnoun's PhD document (UVSQ).

James Roberts gave a lecture on "Traffic management in the future Internet" at 1st SISCom-Bretagne research school on Networks and Telecommunications, U. Rennes, 30/06. He lectured to third year students at Telecom ParisTech on "Traffic management and the future Internet" 30/09. He was jury member for the thesis defense of L. Masoullié (HDR, LIP6), I. Houidi (INT), C. Cardenas (Telecom ParisTech), Z. Ben Houidi (LIP6), J-L. Rougier (HDR, Telecom ParisTech). He gave talks at the workshop Mama, ITC conference and Globecom.

7.3. Conference and workshop committees, invited conferences

Mathieu Feuillet gave a talk on “Stability of ow-aware CSMA” at the conference Performance’2010 in Namur 11/15-19.

Philippe Robert gave talks at the University of Columbia (January 2010), Stochastic Networks Workshop in Cambridge (March 2010), a set of three lectures at the Workshop on Stochastic Processes in Communication Networks for Young Researchers (June 2010). He gave a talk at the conference “A star is born” in Eurandom (December 2010). *Philippe Robert* was invited at the University of Columbia (3 days), Isaac Newton Institute in Cambridge (2 weeks in March), Oberwolfach center (one week in October). *Philippe Robert* was TPC member for ACM Sigmetrics 2010, ITC’22 and Performance 2010.

James Roberts gave an invited talk on PON performance at a workshop organized by Technicolor, 04/21 and at the workshop “MAMA” (MAthematical performance Modeling and Analysis), Columbia University 06/18. He visited Bell Labs, New Jersey on 06/14 for talks on optical networking. He was TPC member for Infocom 2011, ICC’11 CQRM, ONDM 2011, ITC 22.

Florian Simatos gave a talk at the ACM sigmetrics conference.

8. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journal

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[2] T. BONALD, M. FEUILLET. *On the stability of flow-aware CSMA*, in "Performance Evaluation", November 2010, vol. 67, p. 1219–1229.

[3] Y. CHABCHOUB, C. FRICKER, F. GUILLEMIN, P. ROBERT. *On the Statistical Characterization of Flows in Internet Traffic with Application to Sampling*, in "Computer Communications", 2010, vol. 33, n^{o} 1, p. 103–112, http://arxiv.org/abs/0902.1736.

[4] C. FRICKER, F. GUILLEMIN, P. ROBERT. *An identification problem in an urn and ball model with heavy tailed distributions*, in "Probability in the Engineering and Informational Sciences", 2010, vol. 24, n^{o} 1, 77—97, http://arxiv.org/abs/0812.2546.

[5] L. LESKELÄ, P. ROBERT, F. SIMATOS. *Interacting branching processes and linear file-sharing networks*, in "Advances in Applied Probability", 2010, vol. 42, n^{o} 3, p. 834–854, http://arxiv.org/abs/0907.0375.

[6] H. MOHAMED, P. ROBERT. *Dynamic tree algorithms*, in "Annals of Applied Probability", 2010, vol. 20, n^{o} 1, p. 26-51, http://arxiv.org/abs/0809.3577.

[7] P. ROBERT. *The Evolution of a Spatial Stochastic Network*, in "Stochastic Processes and Applications", 2010, vol. 120, n^{o} 7, p. 1342–1363, http://arxiv.org/abs/0908.3256.

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International Peer-Reviewed Conference/Proceedings

[10] N. ANTUNES, C. FRICKER, P. ROBERT, J. ROBERTS. *GATE-driven Dynamic Bandwidth Allocation for WDM EPON*, in "GLOBECOM 2010", Miami, IEEE Communications Society, 2010, http://arxiv.org/abs/1002.2384.

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[12] N. ANTUNES, G. JACINTO, A. PACHECO. *An Analytical Framework to Infer Multihop Path Reliability in MANETs*, in "ACM-Sigmetrics", New-York, ACM, June 2010.

[13] E. COFFMAN, P. ROBERT, F. SIMATOS, S. TARUMI, G. ZUSMAN. *Channel Fragmentation in Dynamic Spectrum Access Systems*, in "ACM-Sigmetrics", New-York, ACM, June 2010, http://arxiv.org/abs/1002.3084.

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Workshops without Proceedings

[15] M. FEUILLET, A. PROUTIÈRE, P. ROBERT. *Random Capture Algorithms: Fluid limits and Stability*, in "Information Theory and Applications Workshop", February 2010.

Scientific Books (or Scientific Book chapters)

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Other Publications

[17] N. ANTUNES, C. FRICKER, J. ROBERTS. *Stability of multi-server polling system with server limits*, june 2010, submitted for publication in Questa.

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