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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Trec

Network Theory and Communications

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THEME COM

Activity Report

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1. Team

TREC is a joint INRIA-ENS project-team.

Head of project team
François Baccelli [DR]

Vice-head of project team
Bartlomiej (Bartek) Błaszczyszyn [CR1]

Administrative assistant
Gabrielle Baron [until September 2004]
Laurence Lenormand [since December 2004]

Staff member
Dohy Hong [CR1, September 2003 – February 2004 “mis à disposition” and since March 2004 “en disponibilité” at N2NSOFT (http://www.n2nsoft.com)]

Scientific adviser
Pierre Brémaud

Research scientist
Thomas Bonald [Research engineer, France Télécom R&D, with TREC since September 2004]
Ki-Baek Kim ["Ingénieur Expert" INRIA]
Alexandre Proutière [Research engineer, France Télécom R&D, with TREC since September 2004]

Ph. D. Students
Charles Bordenave [École Polytechnique and Corps des Télécoms]
Augustin Chaintreau [ENS and Corps des Télécoms; visiting Intel Research Cambridge from September 2004 to August 2005]
Marc Lelarge [École polytechnique, visiting IBM Watson T.J. research center from December 2003 to March 2004, visiting IBM since June 2004]
Julien Reynier [ENS and Corps des Télécoms]
Emmanuel Roy [Université Pierre et Marie Curie]
Minh Anh Tran [École Nationale Supérieure des Télécommunication]

Visiting Scientist
David McDonald [University of Ottawa, with TREC until July 2004]

Intern Students
Anjan Sundaram [August 2004]

2. Overall Objectives

TREC is a joint INRIA-ENS project-team. It is focused on the modeling and the control of communication networks. Its methodological activities are combined with projects defined by industrial partners, notably by Alcatel and France Télécom. The main research directions are :

- packet network communication control: admission control, flow regulation, congestion control, traffic analysis in controlled networks,
- modeling of cellular and ad hoc wireless networks: coverage and load analysis, power control, evaluation and optimization of the transport capacity,
- study of the stochastic network dynamics, in particular by means of algebraic methods,
- developing tools of stochastic geometry and spatial point processes: Voronoi tessellations, coverage processes, random spatial trees, spectral analysis.

3. Scientific Foundations

Here is the scientific content of each of the four principal directions.

- Modeling and control of communication networks. Here we mean control via admission control, flow regulation and feedback control à la TCP, the understanding and improvements of which are major challenges within the context of large networks. Our aim is a mathematical representation of the dynamics of the most commonly used control protocols, from which one could predict and optimize the resulting end user bandwidth sharing and QoS. The design of scalable simulators that could be used for the dimensioning of large IP networks is a first practical outcome of this line of research. The design of multicast overlays based on these common transport protocols is another line of research that is directly linked to the understanding of the dynamics of these protocols.
- Modeling and optimization of cellular and ad hoc wireless networks. The main focus of this line of thought is on the analysis of CDMA networks and of MANETs. A new mathematical representation of interferences based on shot noise has led to a variety of results on coverage and capacity of large CDMA networks when taking into account intercell interferences and power control. The mathematical analysis of the interference and power control problems allowed for the definition of new decentralized admission and congestion control protocols. The interest in these algorithms, besides their potential pertinence for network operators, comes from the fact that they allow for explicit evaluation of several macroscopic characteristics of the network. Our goal is to propose a strategy of the densification and parameterization of the UMTS network. Connectivity and MAC layer protocols for MANETs are currently investigated using a similar approach (additive and max shot noise processes). A new spatial Aloha MAC protocol was proposed that optimizes the transport capacity for ad hoc networks with relaying. The goal is to determine MAC parameters that auto-adapt to the spatial population of users.
- Theory of network dynamics. TREC is primarily interested in pursuing the elaboration of a stochastic network calculus, that would allow the analysis of network dynamics by algebraic methods. The mathematical tools are those of discrete event dynamical systems: semi-rings (max, plus) and inf-convolutions, as well as their non linear extensions (topical and non expansive maps, monotone separable framework); the main probabilistic tools within this framework are ergodic theory, asymptotic analysis, Lyapounov exponent analysis, perturbation analysis and large deviations. The link with certain methods of particle systems such as hydrodynamic limits and mean field limits has allowed us to assess the properties of networks of infinite dimension or infinite population, with quite promising implications to the scalability of TCP based overlay networks.
- Stochastic geometry and the theory of point processes. The theory of point processes on the real line plays a key role in teletraffic analysis. The main mathematical tools studied within this framework are Palm calculus, stochastic intensity and Gibbs fields. Stochastic geometry is particularly useful in all subdomains of communications where planar or spatial components are present: access networks, local loop, multicast trees, distributed games, hierarchical network architectures, in addition to all the wireless network problems listed above. TREC's favorite tools within this framework are Voronoi tessellations, coverage processes, random spatial trees and percolation. See http://www.di.ens.fr/~trec/sg/.

4. Application Domains

We interact with the following industrial partners: France Télécom, Alcatel and IBM.

- The collaboration with FT is focused on two types of applications: the economic analysis of the network which is important because of strong competition between operators and the analysis of protocols having spatial components. Notably, our work is focused on the coverage and capacity of the CDMA/UMTS networks. The current work bears primarily on macrodiversity in UMTS, multisectorial antennas in CDMA, distributed power and admission control for UMTS and associated QoS. Three patents were filed on these questions, one by INRIA and two jointly by INRIA and FT. The pertinence of our approach has already been recognized by Orange. This operator started the implementation of some our methods in its own dimensioning tools.

- The work with Alcatel within the "End to End" OSC with the Network Strategy Group is focused on TCP over wireless and xDSL access. Other activities with Alcatel are pursued jointly with N2NSoft. This concerns DSLAM optimization (with Alcatel Bell Broadband Access) and load balancing in core networks (with RNI Marcoussis).
- With IBM, we work on the design of multicast overlays, both with and without backpressure mechanisms. IBM filled two patents on the matter with INRIA-ENS co-authors.

5. Software

5.1. N2N Software

Keywords: *HTTP traffic*, *TCP*, *access router*, *core router*, *quality of service*, *simulation*.

Participants: François Baccelli, Dohy Hong.

Based on the hybrid simulation methodology of the interaction of a large number of TCP connections designed by TREC, a software tool was developed. The tool allows one to study the characteristics of the rates obtained by each type of user or application under realistic assumptions on traffic (mixing HTTP, Voice, Mail, Video etc) from a detailed description of each network element. This simulation activity was transferred to the start-up N2NSOFT (http://www.n2nsoft.com) created by D. Hong. Currently TREC participates in the adaptation of this methodology to the simulation of new dynamic routing algorithms in core networks within the framework of a collaboration with Alcatel Marcoussis.

5.2. Overlay Multicast Prototype

Keywords: *overlay multicast*, *web*.

Participant: Augustin Chaintreau.

A simulation prototype was designed by A. Chaintreau for the simulation of large multicast overlay networks (see Section 6.1.2). An experimental PlanetLab platform for such overlays was developed and tested in collaboration with IBM.

6. New Results

6.1. Analysis and Optimization of Flow-control Protocols

Keywords: *AQM*, *DSL*, *IP*, *Reno*, *TCP*, *Tahoe*, *additive increase multiplicative*, *bit error*, *congestion prevention/control*, *decrease algorithm*, *delay compensation*, *feedback control*, *hybrid system*, *multicast*, *packet error*, *simulation*, *stability*, *synchronization*, *transmission error*, *wireless AIMD flow model*.

Participants: François Baccelli, Augustin Chaintreau, Danny De Vleeschauwer, Ki-Baek Kim, Zhen Liu, David McDonald, Julien Reynier, Anton Riabov.

A methodology to analyse traffic and congestion control mechanisms is a prerequisite for operators to do resource planning (buffer capacities and bandwidth) capable of handling every kind of trafic mix (voice, video and data) ensuring predefined end to end QoS bounds for various functioning parameters. Several research actions were pursued on the matter.

6.1.1. Mean Field Analysis of Interacting TCP Flows

Mean field limits have allowed us to assess properties of networks of with very large population.

6.1.1.1. Mean field model for interacting HTTP flows

In publication [14] we discussed the mean field limit of a model for multiple HTTP sources multiplexed through a drop-tail router. The HTTP traffic, that is responsible for a large portion of the data transported today on communications network, is the result of the interplay between two mechanisms : Instantaneous bandwidth sharing implemented by TCP, and dynamic properties of the traffic demand of each source, which alternates between requests of documents with varying sizes and period of inactivity. We analyzed the interplay between these two mechanisms using the hybrid Additive Increase Multiplicative Decrease (AIMD) model. Under memory-less assumptions on document size and think time, we can identify and analyze two possible steady state regimes for the mean field limit : a congestion-free steady state, where traffic is interactionless, and a periodic congestion steady state, where throughput is regulated by packet losses.

For certain parameter settings, we observed numerically that the system may reach one of these two regimes or the other depending only on the initial phasing of flows. The fact that a congestion steady state could be reached in cases where an interactionless regime is also possible may be seen as an analogue of turbulence.

These results were further understood by an analysis based on a PDE evolution equation of the instantaneous distribution of rates. It was possible to prove in this setting that such a phenomenon is present for an old version of the TCP protocol (TCP Tahoe). The argument of the proof do not apply in the same form for the current dominant version of TCP (TCP Reno) although the numerical evidence remains. Simulations with a discrete event simulator were further conducted to show that this phenomenon may also be present in the packet-level dynamics of the TCP protocol.

In the prelimit with a finite number of sources the above regimes merge into a single metastable regime: we observe rare transitions between the fluid interactionless regime and the turbulent interaction regime. In the paper[17] we outline a general framework for describing these metastable regimes.

The AQM case was also studied in [26]. In this paper, we derive a closed form formula for the average rate attained by a non persistent TCP source which alternates between idle periods and download periods subject to a fixed packet loss probability. We also derive closed form expressions for the mean time to transfer a file and for the distribution of the transmission rate. Several distributions for the file sizes and idle times are considered including heavy tailed distributions. The formula for the mean transmission rate is shown to boil down to the classical square root mean value formula for persistent flows when the average file size tends to infinity. Using fixed point methods, these formulae can be applied to predict bandwidth sharing among competing HTTP flows subject to Active Queue Management.

6.1.1.2. Mean field analysis of TCP flows with transmission errors and congestion losses

In [16], we analyzed the performance of a large population of a single class of long lived TCP flows experiencing random packet losses due to both random transmission errors and congestion created by the sharing of a common tail drop bottleneck router.

In [25], we analyzed the performance of a large population composed of several classes of long lived TCP flows experiencing packet losses due to random transmission errors and to congestion created by the sharing of a common tail-drop or AQM bottleneck router. Each class has a different transmission error rate. This setting is used to analyze the competition between wired and wireless users in an access network, where one class (the wired class) has no or small (like BER in DSL) transmission error losses whereas the other class has higher transmission error losses, or the competition between DSL flows using different coding schemes. We proposed a natural and simple model for the joint throughput evolution of several classes of TCP flows under such a mix of losses. Two types of random transmission error losses are considered: one where losses are Poisson and independent of the rate of the flow, and one where the losses are still Poisson but with an intensity that is proportional to the rate of the source. We showed that the large population model where the population tends to infinity has a threshold (given in closed form) below which there are no congestion losses at all in steady state, and above which there is a stationary limiting regime in which we can compute both the mean value and the distribution of the rate obtained by each class of flow. We also showed that the maximum mean value for the aggregated rate is achieved at the threshold.

6.1.1.3. Mathematics of mean field

If N stochastic dynamical systems are coupled together through the use of a common resource one may describe the entire system via a histogram of all N states. In the mean field limit as $N \to \infty$ this histogram tends to a deterministic density. The publication [46] provides a new approach to this mean field convergence problem. This publication has now been accepted subject to revision by the Annals of Applied Probability. This approach which first allowed us to analyse RED is now being extended to the case of non persistent sources through one router.

6.1.2. The One to Many TCP Overlay

We pursued the study of multicast group communication supported by an overlay network. In this type of architecture the data are sent by the source to a first set of end-systems using distinct TCP connections; these end-systems in turn transmit the data to a further set of end-systems, through new and distinct TCP connections. The forwarding mechanism between end-systems is thus organized in a tree rooted at the source.

We have analyzed the properties of the group communication on such an overlay network, focusing on reliability and throughput performance in the case where the memory available in each end-systems is finite. Buffer overflows may occur at intermediate end-systems as TCP connections used further in the tree may not be able to transmit data at the same speed as that of the input of the end-system. These losses must be prevented and the throughput should therefore be adapted in a scalable way.

- We have shown that this scheme can be made reliable with a small addition to the current TCP implementation : a local constraint on the communication, called back-pressure, that allows an end-system to stop the emission of packets by upstream nodes when his local-memory is full. This modification may have a great impact on the performance of the system, in particular if the group is very large, as long delays or degraded network conditions in any link can impact the throughput of data everywhere in the tree.
- We were able to prove that such overlays are scalable in the sense that the group throughput is bounded from below by a positive constant that does not depend on the size of the group. This result was obtained using a technique of first-passage percolation on random graphs under the following assumptions: the multicast tree has a bounded degree, perturbations due to cross traffic are light tailed and independent in time.
- Another possible cause of unreliability for this scheme is the failure of an end-system, as the communication relies on a collaborative scheme. We have proven that if the maximal number of simultaneous failures is bounded, the tree is able to recover all the lost pieces of information, and to reconfigure its topology with the same maximal degree. This comes at the cost of an additional finite backup memory in each end-system.

This work, made in collaboration with the research group “Systems and Optimization” of IBM Waston T.J. laboratory, resulted in the proposal of an architecture named “The one-to-many TCP Overlay”. It is currently patented ; the results obtained have been accepted for publication and will be presented at the IEEE Infocom conference in 2005.

6.1.3. Control Theory for TCP Flows

Since end-users of an IP network do not know what capacity they can be allocated, they require a dynamic window-based mechanism like TCP which provides some feedback information about congestion. However, existing AQM (active queue management) schemes have not focused on the kind of control structures that are necessary to control such closed-loop systems. In addition, they do not consider how to handle input/state constraints, time-varying systems, disturbances. In order to address these issues, we develop here some advanced techniques based on receding horizon control (RHC).

6.1.3.1. Stabilizing receding horizon control schemes for constrained linear systems

Receding horizon control (RHC) uses the current control law obtained by solving the optimization problem every sampling instant. Since receding horizon control can consider a finite horizon cost function, it can easily handle input/state constraints, time-varying systems, uncertain systems, etc. For this reason, it has been widely investigated in theory and in practice. In [12], we propose new receding horizon H_∞ control (RHHC) schemes for linear input-constrained discrete time-invariant systems with disturbances. We show that the resulting RHHCs guarantee closed-loop stability in the absence of disturbances and H_∞ norm bound for 2-norm bounded disturbances. In [13], we propose two schemes: a stabilizing intervalwise RHHC for continuous time-varying systems that has a flexible computation time and guarantees a H_∞ norm bound; and another stabilizing intervalwise RHHC with integral control action for time-invariant systems that makes the tracking error approach zero asymptotically for a constant tracking command as well as satisfies a H_∞ norm bound. Finally, in [11], we propose a generalized stabilizing RHC scheme for input/state constrained linear discrete time-varying systems that improves feasibility and on-line computation on the constrained finite-horizon optimization problem, compared with existing schemes.

6.2. Design of Cellular and Ad Hoc Wireless Networks

Keywords: *Boolean model*, *CDMA/UMTS*, *CSMA*, *Hiperlan*, *IEEE 802.11*, *MAC protocols*, *Voronoi tessellation*, *ad hoc networks*, *admission and congestion control*, *capacity*, *coverage*, *point processes*, *shot-noise*, *signal to interference ratio*, *spatial modeling*, *stability transport capacity*, *stochastic geometry*.

Participants: François Baccelli, Bartek Błaszczyszyn, Thomas Bonald, Charles Bordenave, Mohamed Karray, Paul Muhlethaler, Alexandre Proutière, Minh Anh Tran.

This axis concerns the analysis and the design of wireless communication networks, in particular CDMA/UMTS and ad hoc networks. We are interested both in macroscopic models, which are particularly important for economic planning and in models allowing the definition of optimized protocols. Our approach combines several tools and in particular stochastic geometry.

6.2.1. Admission/Congestion Control and Maximal Load in Large CDMA Networks

This work is focused on the influence of geometry on the combination of inter-cell and intra-cell interferences in the downlink of large CDMA networks. We used an exact representation of the geometry of the downlink channels to define scalable admission and congestion control schemes, namely schemes that allow each base station to decide independently of the others what set of voice users to serve and/or what bit rates to offer to elastic traffic users competing for bandwidth. We studied the load of these schemes when the size of the network tends to infinity using stochastic geometry tools. By load, we mean the distribution of the number of voice users that each base station can serve and that of the bit rate offered to each elastic traffic user.

In our approach, the localization of both the antennas and the mobiles is represented by point processes on the plane. The necessary and sufficient condition for the feasibility of the uplink and the downlink, globally in the network, is related to the spectral radius of some random, infinite matrix of the path loss, whose entries depend on the locations of the points of both point processes. In a first article [34] we proposed a sufficient condition for the feasibility of the downlink power allocation, that is based on the sub-stochasticity of the path loss matrix. This approach permits the analysis of the load of each base station cell in a decentralized way, considering only its own users and locations of other base stations. In certain cases, for example for the Poisson point process of antennas and mobiles, this approach gives an explicit closed form solution for the mean global capacity of the network. In particular, given the density of the base stations we found the density of the users that can be served by the network. The approach adopted in this paper leads to some decentralized admission and congestion control schemes. These protocols are subject to a pending INRIA patent.

6.2.1.1. Uplink and downlink with maximal power constraints

In [7] we extend our approach to the uplink and took into account the existence of maximal power constraints of the base stations and users. Moreover, in hexagonal network, using Gaussian approximations for the total load imposed on a given cell by all users served in it, we gave explicit formulas for the infeasibility probability; i.e., for the probability that a Poisson population of a given intensity cannot be entirely accepted by the base station running our admission control protocol. The refinement of the admission and congestion control protocols that take into account maximal base station powers and user powers in both uplink and downlink lead to two joint INRIA-France Telecom patents.

6.2.1.2. Blocking rates via a spatial Erlang formula

In [33] we show that the notion of infeasibility probability is closely related to the notion of blocking probability; i.e., to the fraction of users that are rejected by the admission control policy in the long run, a notion of central practical importance within this setting. The relation between these two notions is not bound to our particular admission control schemes, but is of a more general nature, and in a simplified scenario can be identified with the well-known Erlang loss formula. Namely, the feasibility probability (i.e., the complement of the infeasibility probability) is the normalizing constant (called also the partition function) in the classical loss formula for a general loss network. We prove this relation using a general spatial birth-and-death process, where customer locations are represented by a spatial point process that evolves over time as customers arrive or depart. This allows our model to include the exact representation of the geometry of inter-cell and intra-cell interferences, which play an essential role in the load indicators used in these cellular network admission control schemes.

Our spatial Erlang formula together with previously developed explicit formulas for the feasibility probability, allows for analytical expressions of the fundamental relations between key engineering parameters of the CDMA network and the performance metrics. These relations make possible more systematic studies of several important practical questions concerning QoS, capacity and dimensioning of the network. Their pertinence has already been recognized by Orange. This operator implemented the spatial Erlang formula in its own dimensioning tools.

6.2.1.3. Macrodiversity

We extended our mathematical model of CDMA networks to a model where the base stations are jointly encoding and decoding signals. This kind of cooperation between base stations is called macrodiversity. On the downlink, mobiles are receiving a signal from several antennas and on the uplink, mobiles are sending a signal which is received by several antennas. The gain obtained with macrodiversity is still an open issue and no admission control protocol has been proposed for these networks.

For the downlink, our mathematical model is an extension of the model developed in [34]. We have derived some interesting counter intuitive results on macrodiversity. In particular, we have proved that the number of mobiles receiving a signal from more than two different antennas is bounded above by the number of antennae. Indeed, macrodiversity on the downlink does not drastically improve the feasibility of the power allocation problem.

However, on the uplink, macrodiversity has a much deeper impact on the network. We have extended the results of Hanly [43] to infinite networks and proved that if macrodiversity is enforced the feasibility condition depends only on the mean number of users per base station and the average bit rate required by users. In complete opposition with what happens on the downlink, the geometry of the network does not play any role.

These results have been submitted to publication and are presented in the research report [27].

6.2.1.4. Stability of data flows on a CDMA network

Wireless networks provide new models for queuing theory. The users in the network want to receive data from the network. A fixed bit rate is no longer needed and the key feature is now the maximum number of bits per surface unit and time unit the network can handle without saturation.

This model is driven by applications: stability of data flows is a high stake of next generation wireless networks. We have derived the stability region of CDMA networks in traditional cell structure and in macrodiversity. In particular we have proved that macrodiversity does not increase the stability region of the wireless networks. This work is contained in research reports [29] and [28].

6.2.2. Downlink Capacity of Cellular Networks with Data Traffic

Unlike voice calls that are characterized by their duration, data flows are characterized by their size (in bits). The corresponding traffic intensity, defined as the product of the flow arrival rate by the mean flow size (in bits/s), may well exceed the cell capacity in the sense that the number of data flows increases continuously. Thus we defined the cell capacity as the maximum traffic intensity such that the system remains stable. We applied this notion of various technologies including TDMA, CDMA and OFDM, and compared the results to the maximum capacity given by the information theory [35].

6.2.3. Mobile ad Hoc Networks

The exact representation of signal to interference ratio based on stochastic geometry has shed light on two problems of central importance in MANETs

- connectivity, most often analyzed under (over)simplified Boolean model representations, is in fact not always improved by densification as recently shown with O. Dousse and P. Thiran of EPFL;
- MAC protocols can be optimized for maximizing the network total transport capacity as shown via a collaboration with P. Muhlethaler of Hipercom that is again based on additive and maximal shot noise representations of interferences.

6.2.3.1. Connectivity in MANETs

In the paper [41], we studied the impact of interferences on the connectivity of large-scale ad-hoc networks using percolation theory. We assumed that a bi-directional connection can be set up between two nodes if the signal to noise ratio at the receiver is larger than a certain threshold. The noise is the sum of the contributions of interferences from all other nodes, weighted by a coefficient γ representing an orthogonality factor and of a background noise. We found that there is a critical value of γ above which the network is made of disconnected clusters of nodes. We also proved that if γ is non zero but small enough, there exist node spatial densities for which the network contains a large (theoretically infinite) cluster of nodes, enabling distant nodes to communicate in multiple hops. This paper will appear in IEEE ToN.

6.2.3.2. An Aloha protocol for multihop mobile wireless networks

In [18] we define an Aloha type access control mechanism for large mobile, multihop, wireless networks. The access scheme is designed for the multihop context, where it is important to find a compromise between the spatial density of communications and the range of each transmission. More precisely, we optimize the product of the number of simultaneously successful transmissions per unit of space (spatial reuse) by the average range of each transmission. The optimization is obtained via an averaging over all Poisson configurations for the location of interfering mobiles in a model where an exact evaluation of signal over noise ratio is used. The main mathematical tools stem from stochastic geometry and are spatial versions of the so called additive and max shot noise processes. The resulting MAC protocol can be implemented in a decentralized way provided some local geographic informations are available to the mobiles. This MAC protocol shows very interesting properties. First its transport capacity is proportional to the square root of the density of mobiles and its stability can be shown under mobility conditions discussed in this paper. The delay provided by this protocol for transporting information from one node to any another node is proportional to the distance between them and to the square root of the network density. Furthermore this protocol is self adapting to the network density; more precisely to the best of the authors knowledge, it is the first protocol to reach the Gupta and Kumar bound that does not require prior knowledge of the node density.

6.3. Network Dynamics

Keywords: *Jackson networks*, *Lyapounov exponent*, *Veraverbeke's theorem*, *Whittle network*, *insensitivity*, *max plus algebra*, *monotone-separable networks*, *sub-additivity*, *sub-exponential distribution*.

Participants: François Baccelli, Thomas Bonald, Marc Lelarge, Serguei Foss, Alexandre Proutière.

6.3.1. Insensitivity Property of Queueing Networks

In modern computer-science and telecommunication networks, it is advisable to share the resources so that, as for the telephone networks, the performance of these systems does not depend on the fine characteristics of the traffic generated by users. Thus for the data networks, one could identify the allowance of bandwidth ensuring that the average time of transfer of a queue depends only on the intensity of traffic and not on the distribution of the size of queues. This result uses a class of networks of processor-sharing queues for which the property of insensitivity is equivalent to a property of balance known since works of Kelly and Whittle.

We want to identify "the" class of insensitive queueing networks, i.e. to extend the preceding result with disciplines of service more general than processor sharing. A first result indeed shows that a "symmetric" queueing network satisfying the property of balance is insensitive. It remains to show the reciprocal one, i.e. to determine if this class constitutes the set of insensitive queueing networks.

6.3.2. Stability of Overloaded GPS Queues

In [44], we construct the stationary workload at each queue of a GPS system under fairly general stochastic assumptions, namely stationarity and ergodicity. This construction is quite simple in the case $\rho < 1$ where ρ is the total load of the system. In the case $\rho \geq 1$, we show that there are still some queues that can be stable in the following sense: for any initial condition the workload process of these queues couples in finite time with an unique stationary workload process. For the unstable queues, we show the existence of a mean service rate and give its expression in closed form.

6.3.3. Large Deviations of Monotone Separable Networks

In [44], we derive large deviations results for a monotone separable network. We choose an original approach inspired from works of Ganesh [42] and Toomey [47]. We study a state variable of the stationary network and derive upper and lower bound for the decay rate of its distribution. We use Chernoff's inequality for the upper bound and the large deviations results of [47] to obtain the lower bound. We are able to show that in the case of event graphs these bounds coincide.

6.3.4. Heavy Tail Asymptotics and Long Range Dependence

The theory of rare events for subexponential networks was developed (almost from scratch) via a 4 year long collaboration between TREC and S. Foss. Among the main results, we would quote the tail behavior of the end to end delay in max plus networks, and the tail behavior of workload in generalized Jackson networks, together with new developments on networks of the same classes based on fractional Gaussian processes.

6.3.4.1. Asymptotics of subexponential max-plus networks: the stochastic event graph case

In a joint work with Serguei Foss from Heriot-Watt University [8], we calculated the exact tail asymptotics of stationary response times for open stochastic event graphs, in the irreducible and reducible cases. These networks admit a representation as (max,plus)-linear systems in a random medium. We studied the case of renewal input and i.i.d service times with subexponential distributions. We showed that the stationary response times have tail asymptotics of the same order as the integrated tail of service times. The multiplicative constants only involve the intensity of the arrival process and the (max,plus)-Lyapunov exponents of certain sequences of (max,plus)-matrices associated to the event graph.

6.3.4.2. Tails in generalized Jackson networks with subexponential service distributions

In the case of generalized Jackson networks, we focused on a key state variable, already used in the past for determining the stability region of such networks [32], which is the time to empty the network after stopping the arrival process. We studied the case of renewal input, Markovian routing and i.i.d. service times with subexponential distributions. In a joint work with Serguei Foss [24], we derived the exact asymptotics for the tail of this state variable in the stationary regime.

6.3.4.3. Asymptotic tail distribution of end-to-end delay in networks of queues with self-similar cross traffic

In a joint paper with Zhen Liu and Cathy Xia from IBM T. J. Watson Research Center [22], we considered the steady state distribution of the end-to-end delay of a tagged flow in queueing networks where the queues have self-similar cross traffic. We assume that such cross traffic at each queue, say queue i, is modeled by fractional Brownian Motion (FBM) with Hurst parameter $H_i \in [1/2, 1)$, and is independent of other queues. The arrival process of the tagged flow is renewal. Two types of queueing networks were considered. We showed that the end-to-end delay of the tagged flow in a tandem queueing network, and more generally in a tree network, is completely dominated by one of the queues. The dominant queue is the one with the maximal Hurst parameter. If several queues have the same maximal Hurst parameter, then we have to compare the ratio $\frac{(1-\rho)^H}{\sigma}$ to determine the dominant queue, where ρ is the load of the queue. In the case where the tagged flow is controlled through a window based congestion control mechanism, the end-to-end delay is still asymptotically Weibullian with the same shape parameter. We provided upper and lower bounds on the constant that determines the scale parameter of the corresponding Weibull distribution.

6.3.5. Fluid Stochastic Networks

In [30], we used a sample-path technique to derive asymptotics of generalized Jackson queueing networks in the fluid scale, namely when space and time are scaled by the same factor n. The analysis presupposes only the existence of long-run averages and is based on some monotonicity and concavity arguments for the fluid processes. The results provide a functional strong law of large numbers for stochastic Jackson queueing networks since they apply to their sample paths with probability one. The fluid processes were shown to be piece-wise linear and an explicit formulation of the different drifts is given. In particular, this fluid limit gives a simple computation of the constant $\gamma(0)$ that appears in the stability condition for such networks as demonstrated in [31].

The joint paper with R. Agrawal and R. Rajan on fluid max plus networks appeared in Mathematics of Operations Research [6].

6.4. Stochastic Geometry and Point Processes

Keywords: *Bartlett spectral measure*, *Boolean model*, *Hawkes process*, *Voronoi tessellation*, *dead-leaves model*, *double-stochastic Poisson Process*, *multicast*, *non-homogeneity*, *spatial point process*, *spatial trees*.

Participants: Pierre Brémaud, Bartek Błaszczyszyn, Yann Gousseau, Laurent Massoulié, Emmanuel Roy, René Schott, Andréa Ridolfi, Fançois Roueff, Konstantin Tchoumatchenko.

This year our work is focused on spectral analysis of point processes and approximations of non-homogeneous Voronoi tessellations, coverage processes and percolation.

6.4.1. Second Order Properties of Random Fields and of Point Processes

This axis concerns spectral analysis of processes related to point processes: random sampling processes, shot noises, and the point processes themselves, for example Hawkes processes or point processes with clusters. In [39][37][38] we have presented general formulas for Cramer or Bartlett power spectral measures with respect to a point process that is not necessarily a Poisson, renewal, or Cox, but a general stationary point process whose Bartlett spectrum is known. Such a generality is needed in many circumstances. For example, using the results of this basic theoretical research, in [19][20], we present the calculation of the spectra of complex signals used in ultra-wide bandwidth.

6.4.2. Spectrum of Infinitely Divisible Point Processes

We have investigated some properties of the spectrum of square integrable point processes in a large class of process that can be obtained as the superposition of an arbitrary number of independent processes whose distribution is uniquely determined. Poisson process, Hawkes process, Hawkes process without ancestors, cluster-invariant process all belong to this class. Metric properties in term of their spectrum are studied.

6.4.3. Approximate Decomposition of Modulated-Poisson Voronoi Tessellations

Approximate decomposition is a technique of the approximation of the inhomogeneous models by the results obtained for the homogeneous ones. Mathematical formalization of this technique requires estimations of the errors of approximation.

In [21] we consider the Voronoi tessellation of Euclidean plane that is generated by an inhomogeneous Poisson point process whose intensity takes different constant values on sets of some finite partition of the plane. We show that mean functionals of a cell with the nucleus located in a given set of the partition can be approximated by the mean functionals of the typical cell of the homogeneous Poisson Voronoi tessellation with intensity appropriate to this partitioning set. We give bounds for the approximation errors, which depend on the distance of the nucleus to the boundary of the element of the partition it belongs to. In the case of a stationary random partition, we show that mean functionals of the typical cell of the respective double-stochastic Poisson-Voronoi tessellation admit an approximate decomposition formula. The true value is approximated by a mixture of respective mean functionals for homogeneous models, while the explicit upper bound for the remaining term, which depends on the covariance functions of the random partitioning elements, can be computed numerically for a large class of practical examples. This paper complements the previous studies in [40], where the distribution of the typical cell is approximated. One of the motivations for the study in question is modeling of modern communication networks, where application of the Poisson Voronoi tessellation has already proven to give some interesting results and where the assumption of the homogeneity is often non-adequate.

6.4.4. Dead Leaves Model

The dead leaves model is a well known model of stochastic geometry. In collaboration with François Roueff and Yann Gousseau, Charles Bordenave have generalized some results of Matheron [45] with an extensive use of Palm theory and ergodic theory of point processes. This work has been submitted for publication ([36]). Pierre Calka has joined this research group and a MathStic funding has been obtained for years 2004-2005 to pursue this research.

6.4.5. Performance Characteristics of Multicast Flows on Random Trees

In [9] we consider a flow of data packets from one source to many destinations in a communication network represented by a random oriented tree. By the multicast we understand the ability of some tree vertices to replicate the received packets in a way which depends on the number of destinations downstream. We are interested in several performance characteristics associated with multicast flows on Galton–Watson trees and trees generated by point aggregates of a Poisson process. Such stochastic settings are intended to represent tree-shapes arising in the Internet and in some ad hoc networks. The main result, in the branching process case, is a functional equation for the joint probability generating function of number of packets sent by the root and the total number of transmissions in the whole tree. We provide also conditions for the existence and uniqueness of a solution and a method to compute it using Picard iterations. In the point process case, we use the stochastic comparison technique developed in percolation theory for Boolean models to provide bounds on the introduced characteristics. We use these results to derive a number of characteristics of these random trees and discuss en example of application to analytical evaluation of the loads induced on a network by the multicast session.

7. Contracts and Grants with Industry

7.1. CRE with France Télécom R&D

Participants: François Baccelli, Bartek Błaszczyszyn, Charles Bordenave, Mohamed Kadhem Karray, Jean-Marc Kelif, Mathieu Monfalet, Minh Anh Tran.

Contrat de recherche externalisée (CRE) with France Télécom R&D RESA (ex DMR) represented by Mohamed Kadhem Karray, Jean-Marc Kelif and Mathieu Monfalet entitled “Strategies for the densification of the UMTS network” was signed and realized in 2004.

7.1.1. General perspective

In 2003 TREC proposed a mathematical analysis of the interference in the context of the power control used in CDMA networks. This approach, enriched since this time (see section 6.2.1) in collaboration with researchers from FT R&D, has lead to the definition of a new class of admission and congestion control algorithms. Three patents have been filed on this subject. The interest in these algorithms, besides their potential pertinence for network operators, comes from the fact that they allow for explicit evaluation of several macroscopic characteristics of the network. It is in this sense that our approach is also pertinent to the process of the UMTS network engineering (planning, densification).

The work realized in CRE 2004 is part of a *general perspective of studies leading to the enrichment, validation, refinement and the analysis of possible assets of this novel approach*. In this vein, the works of CRE 2004 constitute a continuation of those undertaken in CRE 2003 and their extension to 2005-2007 is considered. They also complement studies pursued in a spontaneous collaboration between TREC and the researchers of FT R&D.

7.1.2. The main activities in 2004 were:

- A continuation of the adaptation of the developed model, in particular integrating signal propagation characteristics used by FT R&D in the case of directional antennas, macro-diversity and multi-class services. We begun the investigation of the shadowing, a subject that will be continued in 2005.
- A validation of the model with directional antennas and sectoring by the comparison of the analytical results to the simulations performed by FT R&D.
- Analysis of the pertinence of the model to the process of the UMTS engineering in order to propose a strategy of the network densification and parameterization. FT R&D has started in 2004 the implementation of certain analytical methods proposed within this context to an interface module usable with other tools of Orange.

7.2. Opération Stratégique Conjointe with Alcatel Bell " End-to-end performance evaluation of packet communication networks”

Participants: François Baccelli, Augustin Chaintreau, Danny De Vleeschauwer, Dohy Hong, Ki Beak Kim, David Mc Donald, Guido Petit, Julien Reynier.

This project proposes to develop a general methodology for the analysis of the end to end behavior of key IP applications, including both TCP and UDP applications over large networks.

The main scientific questions concern the evaluation/prediction of the end to end performance (mean values and fluctuations of throughput, delay and loss) obtained by individual TCP controlled (resp. UDP) applications under various potential access modes: xdsl, wireless, optical burst etc. and under various IP backbone loading assumptions.

The activities of the current phase are structured in several joint subprojects with researchers of the Network Strategy Group of Alcatel:

- Long lived TCP flows on drop tail wireless access links [16], presented at IEEE Infocom 04, Hong Kong;
- HTTP flows on drop tail access links [14], presented at ACM Sigmetrics 04, New York;
- Competition of DSL and wireless long lived TCP flows on both drop tail and AQM access links [25], to be presented at IEEE Infocom 05, Miami.
- HTTP flows on AQM access links [26], to be presented at QoS IP 05, Catania.

The main direction of research to be investigated next year within the OSC is that of heterogeneity. Other directions include the analysis of AQM networks, a better understanding of finite population models and the design of more accurate statistical models for emerging applications.

Other activities have spined off from the OSC with other groups outside NSG:

- On the analysis of xDSL Networks with the Broadband Access BU of Alcatel Bell.
- On the analysis of load balancing algorithms in core IP networks with RNI Marcoussis.

The OSC has allowed us to hire K.B. Kim and to invite D. Mc Donald who will spend six more months with TREC from January 2005.

7.3. IBM Academic Awards

Participants: François Baccelli, Augustin Chaintreau, Marc Lelarge.

TREC was awarded two IBM Academic Awards to work on overlay networks and on wireless networks. These awards were granted for 2004 and 2005 in relation with the collaboration with the group of Z. Liu of IBM Research, T.J. Watson center, Hawthorne NY. Three publications have been prepared in relation with these awards so far:

- an article [15], which bears on the infinite memory case, was presented at IEEE Infocom 04 in Hong Kong;
- the paper [22], which bears on the analysis of networks with self similar cross traffic, which was also be presented at IEEE Infocom 04;
- a third paper on overlay multicast [23] which bears on the case with backpressure and which will be presented at IEEE Infocom 05.

A prototype was designed and tested. Two IBM patents (with 2 INRIA co-authors) were filled.

The joint research programme already allowed the visit of two PhD students (A. Chaintreau and M. Lelarge).

8. Other Grants and Activities

8.1. Networks and International Working Groups

- TREC is a partner in *ARC TCP*, which includes the Mistral, Armor, Planete and Hipercom project teams of INRIA and other partners like FT R&D, EPFL.
- TREC is a partner in the new *European Network of Excellence (NoE)* called EuroNGI led by Groupement des Ecoles des Télécoms (GET). TREC will be the coordinator of the INRIA participation to this NoE.
- TREC participates in the *AS Informatique et Systèmes Dynamiques*.
- Ch. Bordenave is a member of a working group on stochastic geometry (see Section 6.4.4) that obtained a *MathStic* funding for 2004-2005.

9. Dissemination

9.1. Animation of the Scientific Community

9.1.1. Invited Scientists

Professor David McDonald was visiting TREC on sabbatical leave from the University of Ottawa from June 30, 2003 until July 1, 2004.

9.1.2. TREC's seminar

the following scientists gave talks:

- France
  - Carl Graham (Ecole Polytechnique, Paris), January,
  - Charles Bordenave (ENS, Paris), January and February (2 presentations),
  - Pascal Moyal (ENST, Paris), March,
  - David McDonald (ENS-INRIA TREC and University of Ottawa Canada), March,
  - Irina Ignatiouk (Université de Sergy-Pontoise), April,
  - Marc Lelarge and David Mc Donald (ENS-INRIA TREC and University of Ottawa Canada), April,
  - Emmanuel Roy (ENS), May.
- Europe
  - Volker Schmidt (University of Ulm, Germany), February,
  - Artyom Sapozhnikov (Herion Watt University, Scotland UK), March,
  - Ton Dieker (CWI National Research Institute for Mathematics and Computer Science in the Netherlands), May,
  - Ilkka Norros (VTT Information Technology, Finland), May (2 presentations),
  - Maria-Gabriella Di Benedetto (University of Rome La Sapienza, Italy), June,
  - Hermann Thorisson (Science Institute, University of Iceland), October,
  - Anja Feldmann (Technische Universität München, Germany), November.
- America, Asia and Australia
  - Nicolas Hohn (University of Melbourne, Australia), January,
  - Mark Crovella (Boston University, USA), March,
  - Massimo Franceschetti (University of Berkeley, USA), June,
  - Armand Makowski (University of Maryland, USA), June,
  - Ravi Mazumdar (University of Purdue, Canada), June,
  - Darryl Veitch (University of Melbourne, Australia), October,
  - David Vere-Jones (Victoria University of Wellington, New Zealand), November and December (2 presentations),

9.1.3. Miscellaneous

- TREC animates the project-team seminar: http://www.di.ens.fr/~trec/trec-eng.html
- K.B. Kim animates the project-team reading group.
- B. Błaszczyszyn maintains a web-page on stochastic geometry for communications http://www.di.ens.fr/~trec/sg
- F. Baccelli collaborates with G. Giraudon on the follow up of the interactions between INRIA and FT R&D.
- P. Brémaud is a member of the editorial board of the following journals: *Journal of Applied Probability, Advances Applied Probability, Journal of Applied Mathematics and Stochastic Analysis*;
- F. Baccelli is a member of the editorial board of the following journals: *QUESTA, Journal of Discrete Event Dynamical Systems, Mathematical Methods of Operations Research*.
- B. Błaszczyszyn has published a textbook [4] on life insurance mathematics.
- D. McDonald has published a textbook [5] on applied probability for engineering, mathematics and systems science.

9.2. University Teaching

Télécom Paris Course on queueing theory and network performance evaluation by T. Bonald and A. Proutière (18H);

DEA Probabilités, Paris 6 Graduate Course on Queueing Theory in collaboration with J. Mairesse and L. Massoulié (40h).

Ecole Normale Supérieure, MMFAI Course on Information Theory. of P. Brémaud and C. Bordenave (36h). Undergraduate course (master level) of F. Baccelli, T. Bonald, A. Proutière and Tran Minh Anh on Communication Networks (48H). Undergraduate course (master level) of F. Baccelli, P. Brémaud, J.F. Le Gall and C. Bordenave on applied probability (48h).

Eurandom Course on spatial stochastic models by F. Baccelli, within the framework of the Eurandom Chair, from October 2004 to May 2005.

9.3. Invitations and Participation in Conferences

F. Baccelli

- Member of the scientific board of the MICS NCCR Swiss national project,
- Invited Professor at Stanford University, August 1–September 4,
- Co-organizer of the first workshop on Spatial Stochastic Modeling of Wireless Networks (SpaSWiN 2005), http://www.spaswin.org/, in conjunction with WiOpt 2005, http://www.wiopt.org/.
- Co-organizer of the invited session on Stochastic Geometry and Telecommunication Modeling organized during the 25th European Meeting of Statisticians (EMS'05); July 24-28, Olso, Norway, http://www.ems2005.no/.
- Member of the program committee of the following conferences:
  * Infocom 2004, Hong Kong, China, March 2004, http://www.ieee-infocom.org/2004/
  * Workshop on spatial stochastic modeling, with applications to communications, Edinburgh, June 2004, http://www.ma.hw.ac.uk/icms/meetings/2004/spatstoch/index.html
  * ACM Sigmetrics 2004, New York, NY, USA, June 2004, http://www.cs.columbia.edu/~sigm2004/
- Presentations at the following conferences:
  * IMA Workshop Measuremant, Modeling and Analysis of of the Internet, Minneapolis, USA, January 2004, http://www.ima.umn.edu/complex/winter/c4.html
  * INRIA's Visiting Committee, Paris, March 2004.
  * Infocom 2004, Hong Kong, China, March 2004, http://www.ieee-infocom.org/2004/
  * Three lectures at the L'Aquila Applied Probability Meeting, L'Aquila Italy, April 2004,
  * International Conference on Spatial Point Process Modeling and its Applications (SPPA) Benicassim, Castellón, Spain, April 2004, http://www.sppa.uji.es/
  * Euro NGI Workshop on Mobility and Wireless Networks, Schloss Dagstuhl, Germany, June 2004, http://www-i4.informatik.rwth-aachen.de/content/dagstuhl.htm
  * ICMS Workshop on spatial stochastic modeling, with applications to communications, Edinburgh, June 2004, http://www.ma.hw.ac.uk/icms/meetings/2004/spatstoch/index.html
  * ACM Sigmetrics 2004, New York, NY, USA, June 2004, http://www.cs.columbia.edu/~sigm2004/
  * MTNS 2004, Leuven, Belgium, July 2004, semi-plenary lecture, http://www.mtns2004.be/
  * Workshop ARC-TCP, INRIA Sophia-Antipolis, October 2004.
  * Alcatel ARP Forum, Paris, October 2004, http://www.alcatel.com/technologies/research/arpp/forum2004/
  * Queueing theory and Teletraffic theory, Mittag-Leffler Institut, Stockholm, 2004, http://www.ml.kva.se/program/0405f/workshop.html
- Presentations at the following seminars:

    * Tsinghua University CS, Beijing, on overlay networks, March 04.
    * Imperial College, London, on Spatial Aloha, April 04.
    * INRIA, Sophia Antipolis, on multicast overlays, April 04.
    * Sprint Labs, San Francisco, two lectures on wireless networks, August 04.
    * Berkeley EECS, on HTTP, August 04.
    * Eurandom, Eindhoven, on wireless networks, October 04; inaugural lecture of the Eurandom Chair, November 04.
    * Hamilton Institute, NUI, Dublin, November 2004 on TCP modeling.
    * Intel, Cambridge, UK, November 2004 on MANETs.
    * "Conseil Scientifique" of INRIA, on Cross Layer Optimization, November 04.
- PhD thesis committees: B. Heidergott (Hamburg), S.E. Elayoubi (Lip6), J.B. Gouère (Lyon).

B. Błaszczyszyn

- Co-organizer of the first workshop on Spatial Stochastic Modeling of Wireless Networks (SpaSWiN 2005), http://www.spaswin.org/, in conjunction with WiOpt 2005, http://www.wiopt.org/.
- Co-organizer of the invited session on Stochastic Geometry and Telecommunication Modeling organized during the 25th European Meeting of Statisticians (EMS'05); July 24-28, Olso, Norway, http://www.ems2005.no/.
- Presentations at the following conferences:

    * German Open Conference on Probability and Statistics (Karlsruher Stochastik-Tage) March 2004, http://www.stoch2004.uni-karlsruhe.de/stoch2004/index_en.html,
    * International Conference on Spatial Point Process Modeling and its Applications (SPPA) Benicassim, Castellón, Spain, April 2004 http://www.sppa.uji.es/,
    * VIII Konferencja z probabilistyki, Będlewo, Poland, May 2004, http://www.impan.gov.pl/~prob2002/,
    * Workshop on spatial stochastic modeling, with applications to communications, Edinburgh, June 2004, http://www.ma.hw.ac.uk/icms/meetings/2004/spatstoch/index.html,
    * 16th ITC Specialist Seminar on Performance Evaluation of Wireless and Mobile Systems, University of Antwerp, Belgium, August–September 2004, http://www.itcss16.ua.ac.be/,
    * International Symposium on Voronoi Diagrams in Science and Engineering, Tokyo, Japan, September 2004, http://www.simplex.t.u-tokyo.ac.jp/~vd2004/ (paper presented by René Schott).
- Presentation at the following seminars:

    * Stochastics models seminar (CMAP Ecole Polytechnique), March 2004, http://www.cmap.polytechnique.fr/SEM/Stochastiques.php.
    * Séminaire sur la QoS dans le wireless, Groupe des Ecoles des Télécommunications, June 2004, http://www-rst.int-evry.fr/~chahed/seminaire_wireless.html.

T. Bonald

- Presentations at the following conference:

  * Workshop ARC-TCP, INRIA Sophia-Antipolis, October 2004, http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/ARC_TCP.html.

Ch. Bordenave

- Presentation at the following conferences:

  * German Open Conference on Probability and Statistics (Karlsruher Stochastik-Tage) March 2004, http://www.stoch2004.uni-karlsruhe.de/stoch2004/index_en.html,
  * International Conference on Spatial Point Process Modeling and its Applications (SPPA) Benicassim, Castellón, Spain, April 2004, http://www.sppa.uji.es/,
  * Workshop on spatial stochastic modeling, with applications to communications, Edinburgh, June 2004, http://www.ma.hw.ac.uk/icms/meetings/2004/spatstoch/index.html.

- Presentation at the following seminars:

  * University of Ulm, Faculty of Mathematics and Economics, April, 2004,
  * University of Heriot-Watt, School of Mathematical and Computer Sciences, October, 2004.

P. Brémaud

- Member of the program committee of the 12th INFORMS/APS Conference, Beijing, China, June 2004, http://www.aect.cuhk.edu.hk/~aps/.
- Presentations at the following conferences:

  * International Conference on Spatial Point Process Modeling and its Applications (SPPA) Benicassim, Castellón, Spain, April 2004, http://www.sppa.uji.es/,
  * IEEE International Conference on Communications, Paris, France, June 2004, http://www.icc2004.org/ (paper presented by Andréa Ridolfi),
  * IEEE International Symposium on Information Theory, Chicago, USA, June–July 2004, http://isit2004.org/ (paper presented by Andréa Ridolfi)

A. Chaintreau

- Presentation at the following conferences:

  * IEEE Infocom 2004, Honk Kong, China, March 2004, http://www.ieee-infocom.org/2004/
  * MTNS 2004, Leuven, Belgium, July 2004, http://www.mtns2004.be/

- Participation at the following conferences:

  * ACM Sigmetrics 2004, New York, NY, USA, June 2004, http://www.cs.columbia.edu/~sigm2004/ (short talk in Session Work-In-Progress),
  * Workshop ARC-TCP, INRIA Sophia-Antipolis, October 2004.

- Presentation at the following seminars:
  * IBM T.J. Watson seminar, February and April 2004 (2 talks),
  * Intel Research Cambridge seminar, April 2004,
  * Colloque Jeunes Probabilistes et Statisticiens Aussois JPS 2004 (Meeting for young researchers in probability and statistics), April 2004,
  * LIAFA seminar, Paris, June 2004,
  * INRIA team RESO seminar, Lyon, June 2004,
- Other
  * Presentation for the new ENS class, September 2004.

K.B. Kim

- Presentations at the following conferences:
  * Infocom 2004, Hong Kong, China, March 2004, http://www.ieee-infocom.org/2004/,
  * Workshop ARC-TCP, INRIA Sophia-Antipolis, October 2004, http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/ARC_TCP.html.
- Presentations at the following seminars:
  * ETH (Host: Prof. Manfred Morari), Zurich, Swiss, April 2004,
  * Alcatel, Brussels, Belgium, May 2004,
  * ENS-TREC-Alcatel, Paris, December 2004.

M. Lelarge

- Presentations at the following conferences:
  * Infocom 2004, Hong Kong, China, March 2004, http://www.ieee-infocom.org/2004/,
  * 12th INFORMS/APS Conference, Beijing, China, June 2004, http://www.aect.cuhk.edu.hk/~aps/.
  * Queueing theory and Teletraffic theory, Mittag-Leffler Institut, Stockholm, 2004, http://www.ml.kva.se/program/0405f/workshop.html

D. McDonald

- Member of the program committee of the Ottawa meeting of the Informs Probability Section to be held July 6 to 8, 2005, http://www.stats.uwo.ca/APS2005/
- Organizer of the workshop on rare events sponsored by the Field's Institute to be held at the University of Ottawa on July 4-5, 2005, http://www.fields.utoronto.ca/programs/scientific/05-06/rare_events/
- Presentations at the following conferences:

  - * Infocom 2004, Hong Kong, China, March 2004, http://www.ieee-infocom.org/2004/,
  - * L'Aquila Applied Probability Meeting, L'Aquila Italy, March 2004,
  - * EPLF Summer Research Institute, Lausanne Switzerland, July 2004, http://ic.epfl.ch/page20807.html,
  - * Forty-Second Annual Allerton Conference On Communication, Control, and Computing, Allerton Illinois, USA, September 2004, http://www.csl.uiuc.edu/allerton/.
- – Participation at the following conference
  - * IMS/Bernoulli Society Meeting, Barcelona Spain, July 2004, http://www.imub.ub.es/events/wc2004/,
- – Presentation at the following seminars:
  - * Eurandom, Eindhoven, May 2004, http://www.eurandom.nl/,
  - * Mathematical Institute, University of Wroclaw, Poland, July 2004, http://www.math.uni.wroc.pl/english.html.

A. Proutière

- – Co-organizer of the Workshop on Resource Allocation in Wireless Networks (RAWNET 2005), http://www.rawnet.org/, in conjunction with WiOpt 2005, http://www.wiopt.org/.
- – Presentation at the following conference
  - * Workshop ARC-TCP, INRIA Sophia-Antipolis, October 2004, http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/ARC_TCP.html.
- – Presentation at the following seminar
  - * Queueing theory and Teletraffic theory, Mittag-Leffler Institut, Stockholm, 2004, http://www.ml.kva.se/program/0405f/workshop.html

10. Bibliography

Major publications by the team in recent years

[1] F. BACCELLI, P. BRÉMAUD. *Elements of Queueing Theory*, Série: Applications of Mathematics, second edition, Springer Verlag, 2002.

[2] F. BACCELLI, P. BRÉMAUD. *Modélisation et Simulation des Réseaux de Communication*, Ecole Polytechnique, 2002.

[3] P. BRÉMAUD. *Mathematical Principles of Signal Processing*, Springer-Verlag, 2002.

Books and Monographs

[4] B. BŁASZCZYSZYN, T. ROLSKI. *Introduction to Life Insurance Mathematics*, in Polish: "Podstawy matematyki ubezpieczeń na życie", WNT, 2004.

[5] D. MCDONALD. *Elements of Applied Probability for Engineering, Mathematics and Systems Science*, World Scientific, 2004, http://www.worldscibooks.com/mathematics/5456.html.

Articles in referred journals and book chapters

[6] R. AGRAWAL, F. BACCELLI, R. RAJENDRAN. *An Algebra for Queueing with Time Varying Service Times*, in "Mathematics of Operations Research", n° 29-3, 2004, p. 559–591.

[7] F. BACCELLI, B. BŁASZCZYSZYN, M. KARRAY. *Up and Downlink Admission/Congestion Control and Maximal Load in Large Homogeneous CDMA Networks*, in "MONET", early version in Proc. WiOpt 2003, Sophia Antipolis France, see also INRIA RR 4954, vol. 9, n° 6, December 2004, p. 605–617, http://www.inria.fr/rrrt/rr-4954.html.

[8] F. BACCELLI, S. FOSS, M. LELARGE. *Asymptotics of Subexponential Max Plus Networks; the Stochastic Event Graph Case*, in "Queueing Systems", see also INRIA RR 4952, vol. 46, n° 1–2, 2004, p. 75–96, http://www.inria.fr/rrrt/rr-4952.html.

[9] B. BŁASZCZYSZYN, K. TCHOUMATCHENKO. *Performance characteristics of multicast flows on random trees*, in "Stochastic Models", vol. 20, n° 3, 2004, p. 341–361.

[10] M. GHOSH, D. MCDONALD, S. SINHA. *Zero-Sum Stochastic Games with Partial Information*, in "Journal of Optimization Theory and Applications", n° 121, 2004, p. 99–118.

[11] K. B. KIM. *A Generalized Receding Horizon Control Scheme for Constrained Linear Discrete-Time Systems*, in "IEEE Transactions on Automatic Control", n° 12, 2004.

[12] K. B. KIM. *Disturbance Attenuation for Constrained Discrete-Time Systems via Receding Horizon Controls*, in "IEEE Transactions on Automatic Control", n° 5, 2004, p. 797–801.

[13] K. B. KIM, W. H. KWON. *Intervalwise Receding Horizon H_∞ Tracking Controls for Continuous Linear Time-Varying Systems*, in "IEE Proceedings-Control Theory and Applications", n° 5, 2004, p. 527–531.

Publications in Conferences and Workshops

[14] F. BACCELLI, A. CHAINTREAU, D. DE VLEESCHAUWER, D. MCDONALD. *A mean-field analysis of short lived interacting TCP flows*, in "Proceedings of ACM Sigmetrics, New York, NY, USA", June 2004, p. 343–354, http://www.inria.fr/rrrt/rr-5205.html.

[15] F. BACCELLI, A. CHAINTREAU, Z. LIU, A. RIABOV, S. SAHU. *Scalability of Reliable Group Communication Using Overlays*, in "Proceedings of IEEE INFOCOM'04, Hong Kong", March 2004.

[16] F. BACCELLI, K. B. KIM. *TCP Throughput Analysis under Transmission Error and Congestion Losses*, in "Proceedings of IEEE Infocom, Hong Kong", March 2004.

[17] F. BACCELLI, M. LELARGE, D. MCDONALD. *Metastable Regimes for multiplexed TCP flows*, in "Proceedings of the Forty-Second Annual Allerton Conference on Communication, Control, and Computing, Allerton House, Monticello, Illinois, USA", University of Illinois at Urbana-Champaign, October 2004.

[18] F. BACCELLI, B. BŁASZCZYSZYN, P. MUHLETHALER. *An Aloha Protocol for Multihop Mobile Wireless Networks*, in "Proc. of 16 ITC Sepcialist Seminar, Antwerp, Belgium", see also INRIA RR 4955, September 2004, http://www.inria.fr/rrrt/rr-4955.html.

[19] P. BRÉMAUD, A. RIDOLFI. *Power Spectra of UWB Time-Hopping Modulated Signals: a Shot Noise approach*, in "Proceedings of the IEEE International Symposium on Information Theory, Chicago, USA", 2004.

[20] P. BRÉMAUD, A. RIDOLFI. *Power spectra related to UWB communication*, in "Proceedings of the IEEE International Conference on Communications, Paris", vol. 1, 2004, p. 292–294.

[21] B. BŁASZCZYSZYN, R. SCHOTT. *Approximations of functionals of some modulated-Poisson Voronoi tessellations with applications to modeling of communication networks*, in "Proc. of International Symposium on Voronoi Diagrams in Science and Engineering, Tokyo, Japan", to appear in JJIAM Special Issue on Voronoi diagrams in Science and Engineering ; see also INRIA RR 5323, 2004, http://www.inria.fr/rrrt/rr-5323.html.

[22] M. LELARGE, Z. LIU, C. XIA. *Asymptotic Tail Distribution of End-to-End Delay in Networks of Queues with Self-Similar Cross Traffic*, in "Proceedings of IEEE INFOCOM'04", see also INRIA RR 4951, 2004, http://www.inria.fr/rrrt/rr-4951.html.

Internal Reports

[23] F. BACCELLI, A. CHAINTREAU, Z. LIU, A. RIABOV. *The One-to-Many TCP Overlay: A Scalable and Reliable Multicast Architecture*, to be presented in IEEE Infocom'05, RR, n° 5241, INRIA, Rocquencourt, June 2004, http://www.inria.fr/rrrt/rr-5241.html.

[24] F. BACCELLI, S. FOSS, M. LELARGE. *Tails in Generalized Jackson Networks with Subexponential Service Distributions*, RR, n° 5081, INRIA, Rocquencourt, January 2004, http://www.inria.fr/rrrt/rr-5081.html.

[25] F. BACCELLI, K. B. KIM, D. DE VLEESCHAUWER. *Analysis of the Competition between Wired, DSL and Wireless Users in an Access Network*, to be presented at IEEE Infocom'05, RR, n° 5306, INRIA, Rocquencourt, September 2004, http://www.inria.fr/rrrt/rr-5306.html.

[26] F. BACCELLI, D. MCDONALD. *A Square Root Formula for the Rate of Non Persistent HTTP Flows*, RR, n° 5301, INRIA, Rocquencourt, September 2004, http://www.inria.fr/rrrt/rr-5301.html.

[27] C. BORDENAVE. *Optimal Power Allocation in CDMA Networks with Macrodiversity*, submlitted to IEEE Trans. Inf. Theo., RR, n° 5102, INRIA, Rocquencourt, February 2004, http://www.inria.fr/rrrt/rr-5102.html.

[28] C. BORDENAVE. *Stability of spatial queueing systems*, RR, n° 5305, INRIA, Rocquencourt, September 2004, http://www.inria.fr/rrrt/rr-5305.html.

[29] C. BORDENAVE. *Stability Properties of data flows on a CDMA network in macrodiversity*, RR, n° 5257, INRIA, Rocquencourt, July 2004, http://www.inria.fr/rrrt/rr-5257.html.

[30] M. LELARGE. *Fluid Limit of Generalized Jackson Queueing Networks with Stationary and Ergodic Arrivals and Service Times*, RR, n° 5069, INRIA, Rocquencourt, January 2004, http://www.inria.fr/rrrt/rr-5069.html.

Bibliography in notes

[31] F. BACCELLI, S. FOSS. *Ergodicity of Jackson-type queueing networks*, in "QUESTA", vol. 17, 1994, p. 5–72.

[32] F. BACCELLI, S. FOSS. *On the Saturation Rule for the Stability of Queues*, in "Journal of Appl. Probab.", vol. 32, 1995, p. 494–507.

[33] F. BACCELLI, B. BŁASZCZYSZYN, M. KARRAY. *Blocking Rates in Large CDMA Networks via a Spatial Erlang Formula*, to appear in: Proc. of IEEE Infocom 05..

[34] F. BACCELLI, B. BŁASZCZYSZYN, F. TOURNOIS. *Downlink admission/congestion control and maximal load in CDMA networks*, in "Proceeding of INFOCOM, San Francisco", IEEE, 2003.

[35] T. BONALD, A. PROUTIÈRE. *On the traffic capacity of Gaussian broadcast channels*, submitted, October 2004.

[36] C. BORDENAVE, Y. GOUSSEAU, F. ROUEFF. *The dead leaves model, an example of a general tesselation*, submitted to Adv. in App. Probab., 2004.

[37] P. BRÉMAUD, L. MASSOULIÉ. *Spectra of shot noises and Hawkes branching point processes*, in "Proceedings of IEEE International Symposium on Information Theory, Lausanne, Switzerland", IEEE, June/July 2002, http://isit02.epfl.ch/.

[38] P. BRÉMAUD, L. MASSOULIÉ, A. RIDOLFI. *Power spectral measure and reconstruction error of randomly sampled signals*, in "Proceedings of IEEE Information Theory Workshop, Bengalore, India", IEEE, October 2002, http://ece.iisc.ernet.in/ieee-itw2002/.

[39] P. Brémaud, L. Massoulié, A. Ridolfi. *Power spectra of random spike fields and related processes*, submitted, December 2004.

[40] B. Błaszczyszyn, R. Schott. *Approximate Decomposition of Some Modulated-Poisson Voronoi Tessellations*, in "Advances in Applied Probability", vol. 35, 2003, p. 847–862.

[41] O. Dousse, F. Baccelli, P. Thiran. *Impact of Interferences on the Connectivity of Ad Hoc Networks*, in "Proceedings of INFOCOM, San Francisco", Submission to Transactions on Networking, IEEE, March 2003.

[42] A. Ganesh. *Large deviations of the sojourn time for queues in series*, in "Annals of Operations Research", vol. 79, 1998, p. 3-26.

[43] S. Hanly. *Capacity and power control in spread spectrum macrodiversity networks*, in "Proc. of IEEE Trans. on Comm.", vol. 44, 1996, p. 247–256.

[44] M. Lelarge. *Rare events in networks*, PhD thesis under preparation, 2004.

[45] G. Matheron. *Modèle Séquentiel de Partition Aléatoire*, Technical report, CMM, 1968.

[46] D. McDonald, J. Reynier. *Mean Field Convergence of a model of multiple TCP connections through a buffer implementing RED*, to appear in Annals of Applied Probability, RR, n^o 4850, INRIA, Rocquencourt, July 2003, http://www.inria.fr/rrrt/rr-4850.html.

[47] F. Toomey. *Large Deviations of Products of Random Topical Operators*, in "The Annals of Applied Probability", vol. 12, 2002, p. 317-333.