INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Trec

Theory of networks and communications

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Activity Report

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2. Overall Objectives

2.1. Introduction

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

- modeling and performance analysis of wireless networks: network information theory, coverage and load analysis, power control, evaluation and optimization of the transport capacity, self organization;
- stochastic network dynamics: stability, worst-case performance analysis using the (max,plus) algebra, network calculus, perfect simulation, inverse problems, distributed consensus.
- economics of networks: epidemic risk model, incentives, security, insurance, diffusion of innovations;
- the development of mathematical tools based on stochastic geometry, random geometric graphs and spatial point processes: Voronoi tessellations, coverage processes, random spatial trees, random fields, percolation
- combinatorial optimization and analysis of algorithms: random graphs, belief propagation.

2.2. Highlights

The 2009 survey paper [69] describing the general methodology followed by TREC on the use of stochastic geometry for the design and analysis of wireless networks got the best tutorial paper award of the Communication Society of IEEE for 2010.

3. Scientific Foundations

3.1. Scientific Foundations

- **Modeling and performance analysis of wireless networks.** Our main focus was on cellular networks, mobile ad hoc networks (MANETs) and their vehicular variants called VANETs.

  Our main advances about wireless networks have been based on the development of analytical tools for their performance analysis and on new results from network information theory.

  Concerning cellular networks, the main questions bear on on coverage and capacity in large CDMA networks when taking intercell interferences and power control into account. Our main focus has been on the design of: 1) a strategy for the densification and parameterization of UMTS and future OFDM networks that is optimized for both voice and data traffic; 2) new self organization and self optimization protocols for cellular networks e.g. for power control, sub-carrier selection, load balancing, etc.

  Concerning MANETs, we investigated MAC layer scheduling algorithms, routing algorithms and power control. The MAC protocols we considered are based on Aloha and CSMA as well as their cognitive radio extensions. We investigated opportunistic routing schemes for MANETs and VANETs. The focus was on cross layer optimizations allowing one to maximize the transport capacity of multihop networks.
- **Theory of network dynamics.** TREC is pursuing the analysis of network dynamics by algebraic methods. The mathematical tools are those of discrete event dynamical systems: semi-rings, and in particular network calculus, ergodic theory, perfect simulation, stochastic comparison, inverse problems, large deviations, etc. Network calculus gives results on worst-case performance evaluation; ergodic theory is used to assess the stability of discrete event dynamical systems; inverse problem methods are used to estimate some network parameters from external observations and to design network probing strategies.

  TREC has also been studying gossip based algorithms. These algorithms are a first step towards multi-agents coordination in smart networks. We looked at the convergence of algorithms along random routes to estimate the average of network data. We also developed voting algorithms which compute majority in a distributed way, and our latest research was centered on computing their convergence time.

- **The development of stochastic geometry and random geometric graphs tools.** Stochastic geometry is a rich branch of applied probability which allows one to quantify random phenomena on the plane or in higher dimension. It is intrinsically related to the theory of point processes and also to random geometric graphs. Our research is centered on the development of a methodology for the analysis, the synthesis, the optimization and the comparison of architectures and protocols to be used in wireless communication networks. The main strength of this method is its capacity for taking into account the specific properties of wireless links, as well as the fundamental question of scalability.
- **Combinatorial optimization and analysis of algorithms.** In this research direction started in 2007, we build upon our expertise on random trees/graphs and our collaboration with D. Aldous in Berkeley. Sparse graph structures have proved useful in a number of applications from information processing tasks to the modeling of social networks. We obtained new results for stochastic processes taking place on such graphs. Thereby, we were able to analyze an iterative message passing algorithm for the random assignment problem and to characterize its performance. Likewise, we made a sensitivity analysis of such processes and computed the corresponding scaling exponents (for a dynamic programming optimization problem). We also derived analytic formula for the spectrum of the adjacency matrix of diluted random graphs.
- **Economics of networks** The premise of this relatively new direction of research, developed jointly with Jean Bolot [SPRINT ATL] is that economic incentives drive the development and deployment of technology. Such incentives exist if there is a market where suppliers and buyers can meet. In today's Internet, such a market is missing. We started by looking at the general problem of security on Internet from an economic perspective and derived a model showing that network externalities and misaligned incentives are responsible for a low investment in security measures. We then analyzed the possible impact of insurance. A new research direction started on the economic value of user localization in wireless networks.

4. Application Domains

4.1. Application Domains

We have investigated various applications of our research results with the following industrial partners and user associations:

- **Wireless Networks**
  - Alcatel-Lucent Bell Laboratories (L. Thomas and L. Roulet) on self optimization in cellular networks.
  - Sprint (J. Bolot anf H. Zang) on user localization.
  - Orange (M. Karray) on cellular networks.
- **Network Dynamics**
  - Thalès and Real-Time-at-Work on embedded networks.
  - Grenouille on probing in access networks.
- **Networks Economics**
  - Sprint (J. Bolot) on user localization.

5. Software

5.1. SERT

Participants: Bartłomiej Błaszczyszyn, François-Xavier Klepper.

SERT (Spatial Erlang for Real Time services) was a software designed by M. Karray [Orange Labs, Issy] for the evaluation of various properties of large CDMA networks and in particular the probability that calls are blocked due to the unfeasibility of the power control inherent to CDMA. This tool is based on the research conducted with Orange Labs and is now included in UTRANDIM, a current dimensioning tool of Orange Corporate for UMTS and LTE networks. The original approach of SERT is constantly developed and enriched in collaboration with Orange Labs. In particular this year a research has been undertaken under contract number CRE 46146063-A012 between INRIA and France Télécom (cf. Section 6.1.1.1 and 7.5) on the impact of the shadowing on the quality of service in wireless cellular networks.

5.2. Gibbs' Sampler

Participant: Chung Shue Chen.

The work on the self optimization of cellular networks based on Gibbs' sampler (see Section 6.1.1), carried out in the joint laboratory with Alcatel-Lucent, led to the development of a software prototype that was presented by C. S. Chen at the INRIA Alcatel-Lucent joint laboratory seminar in March 2010 and demonstrated at the Alcatel-Lucent Bell Labs Open Days in May 2010.

5.3. PSI2

Participant: Ana Bušić.

The envelope technique described in Section 6.2 has been implemented in a software tool PSI2 [32], in collaboration with MESCAL team [INRIA Grenoble - Rhône-Alpes].

6. New Results

6.1. Design and Performance Analysis of Wireless Networks

Participants: François Baccelli, Florence Bénézit, Bartłomiej Błaszczyszyn, Chung Shue Chen, François-Xavier Klepper, Mir Omid Haji Mirsadeghi, Frédéric Morlot, Tien Viet Nguyen, Van Minh Nguyen.

This axis bears on the analysis and the design of wireless access communication networks. Our contributions are organized in terms of network classes: cellular networks, wireless LANs and MANETs, VANETs. We also have a section on generic results that regard more general wireless networks. We are interested both in macroscopic models, which are particularly important for economic planning and in models allowing the definition and the optimization of protocols. Our approach combines several tools, queueing theory, point processes, stochastic geometry, random graphs, distributed control algorithms, self organization protocols.

6.1.1. Cellular Networks

The activity on cellular networks has several complementary facets ranging from performance evaluation to protocol design. The work is mainly based on strong collaborations with Alcatel-Lucent, Orange Labs and Sprint.

6.1.1.1. Impact of Shadowing on QoS in Cellular Networks

We studied the impact of the shadowing, as well as the path-loss exponent and the network architecture, on the quality of service (QoS) in wireless cellular networks. This impact is primarily seen in the choice of the mobile's serving base station (BS) as the one received with the strongest signal (and not necessarily the closest one) and on the mobile's *path-loss* with respect to this serving BS. Secondarily, the shadowing impacts the so called mobile's *interference factor*, defined as the ratio of the sum of the path-gains form interfering BS to the path-gain from the serving BS. These are two key ingredients in the analysis of wireless cellular networks, in particular, explicitly present in the analysis of *blocking probabilities* of streaming users. The study of their mean values can explain the behavior of more involved QoS metrics.

Using appropriate stochastic models, we studied numerically the impact of the path-loss exponent and the variance of the shadowing on the blocking probability in the case of hexagonal network architectures. We explained the observed results by the further, numerical and analytical study of the mean path-loss and interference factor in hexagonal networks. We also compared them to these obtained for irregular (Poisson) network architectures. We observe, as commonly expected, that *a strong variance of the shadowing increases the mean path-loss with respect to the serving BS, which in consequence increases the blocking probability*.

We also obtained a surprising result that in some cases *an increase of the variance of the shadowing can significantly reduce the mean interference factor and, in consequence, also the blocking probability*. We confirmed our findings by a mathematical analysis of the respective models. We also obtain *fully explicit, analytical results for the mean path-loss and interference factors in the case of the infinite Poisson network with an arbitrary distribution of the shadowing*.

This research has been undertaken under the 2010 contract CRE 46146063-A012 between INRIA and France Télécom (see Section 7.5). Partial results were presented at IFIP WMNC'10 [25]. A more complete journal paper [60] is under preparation.

6.1.1.2. Self-Optimization of Radio Resources in Cellular Networks

In [33], we developed mathematical and algorithmic tools for the self-optimization of mobile cellular networks. Scalable algorithms which are based on local measurements and do not require heavy coordination among the wireless devices were proposed. We focused on the optimization of transmit power and of user association. The method is applicable to both joint and separate optimizations. The global utility minimized is linked to potential delay fairness. The distributed algorithm adaptively updates the system parameters and achieves global optimality by measuring SINR and interference. The algorithms are built on Gibbs' sampler and offer a unified framework that can be easily used for different purposes.

In [63], we investigated the joint optimization of radio resources in heterogeneous cellular networks made of a juxtaposition of macro and small cells. We showed that within this context, it is essential to use algorithms able to simultaneously solve the problems of channel selection, user association and power control. In such networks, the unpredictability of the cell and user patterns also requires self-optimized schemes. We proposed a generalized solution which is based on Gibbs' sampler. It can be implemented in a distributed way and nevertheless achieves minimal system-wide potential delay. Results show that it is effective in both throughput and energy efficiency.

Three patents were filed under the joint laboratory.

6.1.1.3. Self-Optimization of Neighbor Cell List

In cellular networks, the neighbor cell list (NCL) has an important impact on the number of dropped calls and is traditionally optimized manually with the help of planning tools. In [38], a method for automatically optimizing a NCL was presented, which consists of an initialization using a self-configuration phase, followed by a self-optimization phase that further refines the NCL based on measurements provided by mobile stations during the network operation. The performance of the proposed methods was evaluated for different user speeds and different NCL sizes. Besides, the convergence speed of the proposed self-optimization method was evaluated. It was shown that when about 6000 measurements are reported by mobile stations, the proposed self-optimization method attains a stable maximum performance with a success rate of about 99%.

6.1.1.4. Best Signal Quality in a Wireless Network

In a wireless network composed of randomly scattered nodes, the characterization of the distribution of the best signal quality received from a group of nodes is of primary importance for many network design problems. In [37], we developed a framework for analyzing this distributions using shot noise models for the interference field. We first identified the joint distribution of the interference and the maximum signal strength. We then represented the best signal quality as a function of these two quantities. Particular practical scenarios were also analyzed in which explicit expressions are obtained.

6.1.1.5. Extremal Signal Quality in Small Cell Networks

In [12], we investigated two critical issues pertaining to small cell networks: best signal quality and user mobility management. We showed that under the assumptions that base stations are uniformly distributed in a ring-shaped region and that shadowings are lognormal, independent, and identically distributed, when the number of sites in the ring tends to infinity, then the maximum signal strength received at the center of the ring tends in distribution to a Gumbel distribution when properly renormalized, and it is asymptotically independent of the interference. Using these properties, we derived the distribution of the best signal quality. Furthermore, an optimized random cell scanning scheme was proposed, based on the evaluation of the optimal number of sites to be scanned for maximizing the user data throughput.

6.1.1.6. Cellular Network Tomography

The Foschini-Miljanic's [67] algorithm is used for power control in cellular networks whes users require a fixed bit rate. It leads to an optimal choice of power by the users in a distributed way when such a solution exists. If the users are too greedy or too many, the network saturates, and it is not possible to provide the required bit rates. We have been working on the question of residual bandwidth estimation. The residual bandwidth of a user is defined as the rate that this user should have to saturate the network when all other users stick to their initial rate requirement and all users use power control. The aim is to determine the residual bandwidth of a given user b y local measurements. We showed that by simply changing their SINR target slightly and by listening to the evolution of interference, users can locally inverse Foschini-Miljanic's algorithm and compute their residual bandwidth.

6.1.1.7. A Generic Model for Cellular Networks

Cellular networks are usually modeled by placing the base stations according to a regular geometry such as a grid, with the mobile users scattered around the network either as a Poisson point process (i.e. uniform distribution) or deterministically. These models have been used extensively for cellular design and analysis but suffer from being both highly idealized and not very tractable. Thus, complex simulations are used to evaluate key metrics such as coverage probability for a specified target rate (equivalently, the outage probability) or average/sum rate. More tractable models have long been desirable. In a joint work with J. Andrews and R. Ganti [UT Austin, USA] [16], we developed general models for multi-cell signal-to-noise-plus-interference ratio (SINR) based on homogeneous Poisson point processes and derived the coverage probability and rate. Under very general assumptions, the resulting expressions for the SINR cumulative distribution function involve quickly computable integrals, and in some important special cases of practical interest these integrals can be simplified to common integrals (e.g., the Q-function) or even to exact and quite simple closed-form expressions. We also derived the mean rate, and then the coverage gain (and mean rate loss) from static frequency reuse. We compared the coverage predictions obtained by this approach to the standard grid model and an actual base station deployment. We observed that the proposed model is pessimistic (a lower bound on coverage) whereas the grid model is optimistic. In addition to being more tractable, the proposed model may better capture the increasingly opportunistic and dense placement of base stations in urban cellular networks with highly variable coverage radii.

6.1.2. Mobile Ad Hoc Networks

A MANET is made of mobile nodes which are at the same time terminals and routers, connected by wireless links, the union of which forms an arbitrary topology. The nodes are free to move randomly and organize themselves arbitrarily. Important issues in such a scenario are connectivity, medium access (MAC), routing and stability. This year, in collaboration with Paul Mühlethaler [INRIA HIPERCOM], we mainly worked on the analysis of MAC and routing protocols in multi-hop MANETS.

6.1.2.1. Comparison of Slotted to Non-slotted Aloha for MANETS

In [27] we proposed two analytically tractable stochastic models of non-slotted Aloha for MANETs: a first model assumes a static pattern of nodes while the other assumes that the pattern of nodes varies over time. Both models feature transmitters randomly located in the Euclidean plane, according to a Poisson point process with the receivers randomly located at a fixed distance from the transmitters. The analysis concentrates on the so-called outage scenario, where a successful transmission requires a Signal-to-Interference-and-Noise Ratio (SINR) larger than a given threshold. With Rayleigh fading and the SINR averaged over the duration of the packet transmission, both models lead to closed form expressions for the probability of successful transmission. We show an excellent matching of these results with simulations. Using our models we compared the performances of non-slotted Aloha to the previously studied slotted Aloha. We observed that when the path loss is not very strong, both models, when appropriately optimized, exhibit similar performance. For stronger path loss, non-slotted Aloha performs worse than slotted Aloha. However when the path loss exponent is equal to 4 its density of successfully received packets is still 75% of that in the slotted scheme. This is still much more than the 50% predicted by the well-known analysis where simultaneous transmissions are never successful. Moreover, in any path loss scenario, both schemes exhibit the same energy efficiency.

6.1.2.2. A comparison of Aloha and CSMA in Wireless Ad-Hoc Networks under Different Channel Conditions

In [46] we compared Aloha and Carrier Sense Multiple Access (CSMA) in Wireless Ad-Hoc Networks. We used a Signal-to-Interference-and-Noise Ratio (SINR) model where a transmission is assumed to be successful when the SINR is larger than a given threshold. Regarding channel conditions we considered both negligible and standard Rayleigh fading. For slotted and non-slotted Aloha we use analytical models as well as simulations to study the density of successful transmissions in the network. As it is difÃ¯Â¬?cult to build precise models for CSMA, we used only simulations to compute the performance of this protocol. We compared the two Aloha versions and CSMA on a fair basis, i.e.; when they are optimized to maximize the density of successful transmissions. For slotted Aloha, the key optimization parameter is the medium access probability, for non-slotted Aloha we tune the mean back-off time, whereas for CSMA it is the carrier sense threshold that is adjusted. Our study shows that CSMA always outperforms slotted Aloha, which in turn outperforms its non-slotted version. The gain in the density of successful transmissions depends however on the model's parameters: the path-loss exponent, SINR threshold, the presence or not of the fading, as well as the transmission range. Our conclusions differ from these of the seminal paper by Nelson and Kleinrock (1983), where the performance of Aloha is found comparable to this of CSMA in a simple geometric model, the reason being a non-optimal choice of the sensing range in the latter model.

6.1.2.3. A New Phase Transition for Local Delays in MANETs

Consider again a slotted version of Aloha for MANETS. As above, our model features transmitters randomly located in the Euclidean plane, according to a Poisson point process and a set of receivers representing the next-hop from every transmitter. We concentrate on the so-called outage scenario, where a successful transmission requires a SINR larger than some threshold. In [17] we analyzed the local delays in such a network, namely the number of times slots required for nodes to transmit a packet to their prescribed next-hop receivers. The analysis depends very much on the receiver scenario and on the variability of the fading. In most cases, each node has finite-mean geometric random delay and thus a positive next hop throughput. However, the spatial (or large population) averaging of these individual finite mean-delays leads to infinite values in several practical cases, including the Rayleigh fading and positive thermal noise case. In some cases it exhibits an interesting phase transition phenomenon where the spatial average is finite when certain model parameters (receiver distance, thermal noise, Aloha medium access probability) are below a threshold and infinite above. To the best of our knowledge, this phenomenon, has not been discussed in the literature. We comment on the relationships between the above facts and the heavy tails found in the so-called “RESTART” algorithm. We showed that the spatial average of the mean local delays is infinite primarily because of the outage logic, where one transmits full packets at time slots when the receiver is covered at the required SINR and where one wastes all the other time slots. This results in the “RESTART” mechanism, which in turn explains why we have infinite spatial average. Adaptive coding offers another nice way of breaking the outage/RESTART logic. We showed examples where the average delays are finite in the adaptive coding case, whereas they are infinite in the outage case.

6.1.2.4. Opportunistic Routing in MANETs

In classical routing strategies for wireless ad-hoc (mobile or mesh) networks packets are transmitted on a pre-defined route that is usually obtained by a shortest path routing protocol. In [8] we reviewed some recent ideas concerning a new routing technique which is opportunistic in the sense that each packet at each hop on its (specific) route from an origin to a destination takes advantage of the actual pattern of nodes that captured its recent (re)transmission in order to choose the next relay. The paper focuses both on the distributed algorithms allowing such a routing technique to work and on the evaluation of the gain in performance it brings compared to classical mechanisms. On the algorithmic side, we showed that it is possible to implement this opportunistic technique in such a way that the current transmitter of a given packet does not need to know its next relay a priori, but the nodes that capture this transmission (if any) perform a self selection procedure to chose the packet relay node and acknowledge the transmitter. We also showed that this routing technique works well with various medium access protocols (such as Aloha, CSMA, TDMA). Finally, we showed that the above relay self selection procedure can be optimized in the sense that it is the node that optimizes some given utility criterion (e.g. minimize the remaining distance to the final destination) which is chosen as the relay. The performance evaluation part is based on stochastic geometry and combines simulation a analytical models. The main result is that such opportunistic schemes very significantly outperform classical routing schemes when properly optimized and provided at least a small number of nodes in the network know their geographical positions exactly.

Mathematical analysis of asymptotic properties of opportunistic routing on large distances (when the Euclidean distance between the source and destination node tends to infinity) reveals the following surprising negative result: Under Poisson assumption for the repartition of nodes and some natural assumptions on the wireless channels, the mean delay per unit of distance is infinite. The main positive result states that when adding a periodic node infrastructure of arbitrarily small intensity to the Poisson point process, this “delay rate” is positive and finite (see Section 6.4.4.3 for more details).

6.1.2.5. MAC mechanisms with Performance Guarantees

We worked with P. Bermolen PhD student jointly supervised with Télécom ParisTech, on the design and the quantitative evaluation of MAC mechanisms for wireless ad-hoc networks with performance guarantees. By this, we mean mechanisms where each accepted connection obtains a minimum rate or equivalently a minimum SINR level — which is not guaranteed by CSMA/CA — and which are adapted to the wireless ad-hoc network framework, namely are fully decentralized, power efficient and provide a good spatial reuse. Two such access control algorithms were defined and compared in [19]. Both take the interference level into account to decide on the set of connections which can access the shared channel at any given time. The main difference between the two is the possibility or not of adjusting the transmission power of the nodes. A comparison of the performance of these two mechanisms and CSMA/CA was performed, based on a mix of analytical models and simulation and on a comprehensive set of performance metrics which include spatial reuse and power efficiency. Different network topologies, propagation environments and traffic scenarios are considered. The main aim of our study is to identify which of the proposed mechanisms outperforms CSMA/CA best depending on the scenario.

P. Bermolen defended her thesis [5], jointly supervised with Télécom ParisTech, in February 2010. She now holds a position in Universidad de la República, Montevideo, Uruguay.

6.1.3. Cognitive Radio

In [35] we proposed a probabilistic model based on stochastic geometry to analyze cognitive radio in a mobile ad hoc network using carrier sensing multiple access. Analytical results were derived on the impact of the interaction between primary and secondary users on their medium access probability, coverage probability and throughput. These results give insight on the guarantees which can be offered to primary users and more generally on the possibilities offered by cognitive radio to improve the effectiveness of spectrum utilization in such networks.

In [36], we proposed a comprehensive probabilistic framework which can be used to model and analyze cognitive radio (CR) network using carrier sensing (CS) based multiple access scheme. We then discussed several CR network models as case studies. For each model, analytical results were derived for important performance metrics. This leads to a quantification of the interplay between primary and secondary users in such networks.

In [26] we assumed Aloha for both primary and secondary radio networks, and used previously developed (cf. [2]) analytical models to study how the two radio networks can coexist within the same area. We showed how the primary network and the secondary network can adapt their transmission parameters simultaneously to achieve the following goal: the primary network maintains its performance with a maximum and fixed degradation whereas the secondary network maximizes its transmission throughput. In practice this involves the primary network adapting its transmission power and the secondary network its transmission probability. We also studied the gain in performance when the secondary network nodes only transmit when their receivers are at minimum distance from any transmitter nodes in the primary network (constrained distance deployment).

6.1.4. Vehicular Ad-Hoc Networks (VANETs)

Vehicular Ad Hoc NETworks (VANETs) are special cases of MANETs where the network is formed between vehicles. VANETs are today the most promising civilian application for MANETs and they are likely to revolutionize our traveling habits by increasing safety on the road while providing value added services.

In [47] we studied slotted and non-slotted Aloha medium access schemes in VANETs. To this regard, we considered a one-dimensional, linear network, which is an appropriate assumption for VANETs and differs from two-dimensional, planar models usually assumed for general MANETs. More precisely, we used a linear version of the Poisson bipolar network model proposed in [2] in which the locations of signal emitting vehicles form a homogeneous Poisson point process on the line, and where the receivers are within a fixed distance from these emitters. We use the SINR capture model assuming power-law mean path-loss and independent Rayleigh fading. First, we considered a capture/outage scenario with fixed bit rate coding, where the SINR must be above a given threshold for a successful packet reception. In this setting we obtained explicit formulas to calculate the probability of capture for both slotted and non-slotted Aloha. From these formulas other characteristics, such as the mean density of packet progress, were derived and optimized. We considered also adaptive coding, where the throughput depends on the SINR. In this scenario we quantified and optimized the mean density of information throughput. Our unified approach to slotted and non-slotted Aloha allows for explicit comparison of both versions of this simple MAC. The obtained results differ quantitatively and even qualitatively from these obtained previously in the analogous analysis of planar MANETs, revealing some specificity of the optimal tuning of the MAC layer in the linear network topology.

6.1.5. Generic Wireless Networks

6.1.5.1. Power Control in Wireless Networks

In [64], we studied the weighted sum rate maximization problem in wireless networks consisting of multiple source-destination pairs. The optimization problem is to maximize a weighted sum of data rates by adjusting the power of each user. The problem is in general a non-convex optimization problem that will lead to multiple local maxima. A Gauss-Seidel type iterative power control algorithm was presented. We showed by simulation that the proposed algorithm converges to the global maximum with very high probability, if we initialize the initial power allocation uniformly at random. The proposed algorithm also has the favorable properties that only simple operations are needed in each iteration, and the convergence is fast. Performance comparison under different user densities has also indicated its effectiveness. Finally, we discussed some simple and optimal power allocation strategies under special cases of the problem if the network can be represented by a certain approximation.

6.1.5.2. Conflict-Avoiding Codes

Conflict-avoiding codes are used in the multiple-access collision channel without feedback. The number of codewords in a conflict-avoiding code is the number of potential users that can be supported in the system. In [14], a new upper bound on the size of constant-weight conflict-avoiding codes was proved. This upper bound is general in the sense that it is applicable to all code lengths and all Hamming weights. Several existing constructions for conflict-avoiding codes, which are known to be optimal for Hamming weights equal to four and five, are shown to be optimal for all Hamming weights in general.

6.1.5.3. Simultaneous Decoding

In [55], in collaboration with A. El Gamal [Stanford, USA] and D. Tse [UC Berkeley, USA], we analyzed a network made of a collection of transmitter-receiver links where each link is considered to be part of a Multiple Access Channel (MAC) together with a collection of co-transmitters, rather than treating the messages of the latter as noise. This MAC extension is meant to improve the rate of the link and not to decode the messages of the co-transmitters. The necessary and sufficient condition for the feasibility of some rate when using successive interference cancellation and simultaneous decoding were provided. The reasons why simultaneous decoding is preferable to successive interference cancellation were also given. The gain obtained when using this type of simultaneous decoding rather than treating interference as noise was then quantified in a network made of a large random collection of such links. The gains in coverage and in rate were analyzed in terms of ensemble averages, evaluated using stochastic geometry. Closed form or integral expressions were obtained for the outage/coverage probability in networks where nodes are randomly distributed like a Poisson point process on an infinite plane. In the CDMA limit (large bandwidth, low SINR per hertz, high density), the ensemble average of the link rates tends to 0 when interference is treated as noise whereas it tends to a positive constant when simultaneous decoding of infinite order is used. The whole analysis was conducted in the AWGN case.

6.1.5.4. User Mobility Models

In [34], we analyzed phenomena related to user clumps and hot spots occurring in mobile networks at the occasion of large urban mass gatherings. Our analysis is based on observations made on mobility traces of GSM users in several large cities. Classical mobility models, such as the random waypoint, do not allow one to represent the observed dynamics of clumps in a proper manner. This motivates the introduction and the mathematical analysis of a new interaction-based mobility model, which is the main contribution of the present paper. This model was shown to allow one to describe the dynamics of clumps and in particular to predict key phenomena such as the building of hot spots and the scattering between hot spots, which play a key role in the dimensioning of wireless networks. We showed how to obtain the main parameters of this model from simple communication activity measurements and we illustrate this calibration process on real cases.

6.2. Network Dynamics

Participants: François Baccelli, Florence Bénézit, Anne Bouillard, Ana Bušić, Nadir Farhi, Bruno Kauffmann, Furcy-Alexandre Pin.

This traditional research topic of TREC has several new threads like perfect simulation, active probing or Markov decision.

6.2.1. Network Calculus

Network calculus is a theory that aims at computing deterministic performance guarantees in communication networks. This theory is based on the (min,plus) algebra. Flows are modeled by an *arrival curve* that upper-bounds the amount of data that can arrive during any interval, and network elements are modeled by a *service curve* that gives a lower bound on the amount of service offered to the flows crossing that element. Worst-case performances are then derived by combining these curves.

6.2.1.1. Tight performance bounds in feed-forward networks

In cooperation with Éric Thierry and Laurent Jouhet [ENS Lyon], we described in [22] the first algorithm which computes the maximum end-to-end delay for a given flow, as well as the maximum backlog at a server, for *any* feed-forward network under arbitrary multiplexing, with concave arrival curves and convex service curves. Its computational complexity may look expensive (possibly super-exponential), but we showed that the problem is intrinsically difficult (NP-hard). We showed that, fortunately, in some cases, like tandem networks with cross-traffic interfering along intervals of servers, the complexity becomes polynomial.

6.2.1.2. Feed-forward networks with wormhole routing discipline

In collaboration with Bruno Gaujal [INRIA Rhone Alpes] we are working on a model of performance bound calculus on feed-forward networks where data packets are routed under wormhole routing discipline. We are interested in determining maximum end-to-end delays and backlogs for packets going from a source node to a destination node, through a given virtual path in the network. Our objective is to give a "network calculus" approach to calculate the performance bounds. For this, we propose a new concept of curves that we call packet curves. The curves permit to model constraints on packet lengths for data flows, when the lengths are allowed to be different. We used this new concept to propose an approach for calculating residual services for data flows served under non preemptive service disciplines.

6.2.1.3. Comparison of different classes of service curves in Network Calculus

In envelope-based models for worst-case performance evaluation like Network Calculus or Real-Time Calculus, several types of service curves have been introduced to quantify some deterministic service guarantees. In cooperation with Éric Thierry and Laurent Jouhet [ENS Lyon], we studied in [21] the expressiveness of these different definitions of service curves. We revisited the hierarchy ranging from the most restrictive definition linked to *variable capacity nodes* to the most general definition of *simple service curves* and stated the conditions when the different definitions overlap and discuss the existence of canonical descriptions for systems specified through those definitions.

6.2.1.4. SpaceWire-like switching router

In collaboration with Xavier Olive [Thalès Alenia Space, Toulouse] we are working on an end-to-end delay calculus model for a SpaceWire-like switching router. We applied a new network calculus approach to determine residual services guaranteed for packets passing through a SpaceWire-like router, where wormhole routing discipline is set. Our results on end-to-end delays are compared to the effective delays obtained by "Thalès Alenia Space".

6.2.2. Queueing Theory and Active Probing

6.2.2.1. Inverse Problems

Active probing began by measuring end-to-end path metrics, such as delay and loss, in a direct measurement process which did not require inference of internal network parameters. The field has since progressed to measuring network metrics, from link capacities to available bandwidth and cross traffic itself, which reach deeper and deeper into the network and require increasingly complex inversion methodologies. In [56], we formulated this line of thought as a set of inverse problems in queueing theory. Queueing theory is typically concerned with the solution of direct problems, where the trajectory of the queueing system, and laws thereof, are derived based on a complete specification of the system, its inputs and initial conditions. Inverse problems aim to deduce unknown parameters of the system based on partially observed trajectories. We provided a general definition of the inverse problems in this class and map out the key variants: the analytical methods, the statistical methods and the design of experiments. We also show how this inverse problem viewpoint translates to the design of concrete Internet probing applications.

We also investigated inverse problems in bandwidth sharing networks theory. A bandwidth sharing networks allocates the bandwidth to each flow in order to maximize a given utility function (typically an α-fairness), with the constraints given by the capacity of the different servers. In particular, it has been shown that the equilibrium distribution of the bandwidth allocated by TCP to many competing connections is oscillating around an α-fair allocation. As such, the theory of bandwidth sharing network is a high-level viewpoint of networks. We investigated the meaning of inverse problems in this theory, and how they are related to the active probing paradigm. In two simple examples of network, we showed that the capacity of the different servers and the flow population can estimated, and we provided an algorithm to perform this estimation.

6.2.2.2. Internet Tomography

Most active probing techniques suffer of the "Bottleneck" limitation: all characteristics of the path after the bottleneck link are erased and unreachable. we are currently investigating a new tomography technique, based on the measurement of the fluctuations of point-to-point end-to-end delays, and allowing one to get insight on the residual available bandwidth along the whole path. For this, we combined classical queueing theory models with statistical analysis to obtain estimators of residual bandwidth on all links of the path. These estimators were proved to be tractable, consistent and efficient. In [57] we evaluated their performance with simulation and trace-based experiments.

Lately this method has been generalized in [13] to a probing multicast tree instead of a single path. This work deals with the complexity of the combinatorials in trees, and gives an explicit formula for the iteration of the Expectation-Maximization (E-M) algorithm. The E-M algorithm is notoriously slow, and we provided three speed-up techniques which are effective in our case (up to a factor 10^3 in the computation time). These techniques are general, and can be applied to other instances of E-M, or even several other iterative algorithms.

6.2.3. Perfect Simulation

Perfect simulation, introduced by Propp and Wilson in 1996, is a simulation algorithm that uses coupling arguments to give an unbiased sample from the stationary distribution of a Markov chain on a finite state space $\mathcal{X}$. In the general case, the algorithm starts trajectories from all $x \in \mathcal{X}$ at some time in the past until time $t = 0$. If the final state is the same for all trajectories, then the chain has coupled and the final state has the stationary distribution of the Markov chain. Otherwise, the simulations are started further in the past. This technique is very efficient if all the events in the system have appropriate monotonicity properties. However, in the general (non-monotone) case, this technique requires that one consider the whole state space, which limits its application only to chains with a state space of small cardinality.

6.2.3.1. Piecewise Homogeneous Events.

We proposed in [42] a new approach for the general case that only needs to consider two trajectories. Instead of the original chain, we used two bounding processes (envelopes) and we showed that, whenever they couple, one obtains a sample under the stationary distribution of the original chain. We showed that this new approach is particularly effective when the state space can be partitioned into pieces where envelopes can be easily computed. We further showed that most Markovian queueing networks have this property and we propose efficient algorithms for some of them.

The envelope technique has been implemented in a software tool PSI2 [32].

6.2.3.2. Acceleration of Perfect Sampling by Skipping Events

We present in [59] a new method to speed up perfect sampling of Markov chains by skipping passive events during the simulation. We showed that this can be done without altering the distribution of the samples. This technique is particularly efficient for the simulation of Markov chains with different time scales such as queueing networks where certain servers are much faster than others. In such cases, the coupling time of the Markov chain can be arbitrarily large while the runtime of the skipping algorithm remains bounded. This was further illustrated by several experiments that also show the role played by the entropy of the system in the performance of our algorithm.

6.2.3.3. Probabilistic Cellular Automata

In a joint work with J. Mairesse and I. Marcovici [LIAFA, CNRS and Université Paris 7] [44], we considered probabilistic cellular automata (PCA). In a PCA, the cells are updated synchronously and independently, according to a distribution depending on a finite neighborhood. A PCA can be viewed as a Markov chain whose ergodicity is investigated. A classical cellular automaton (CA) is a particular case of PCA. For a 1-dimensional CA, we proved that ergodicity is equivalent to nilpotency, and is therefore undecidable. We then proposed an efficient perfect sampling algorithm for the invariant measure of an ergodic PCA. Our algorithm does not assume any monotonicity properties of the local rule. It is based on a bounding process which is shown to be also a PCA. We then focused on the PCA Majority, whose asymptotic behavior is unknown, and perform numerical experiments using the perfect sampling procedure.

6.2.4. Bounds for Markov Chains

Solving Markov chains is in general difficult if the state space of the chain is very large (or infinite) and lacking a simple repeating structure. One alternative to solving such chains is to construct models that are simple to analyze and provide bounds for a reward function of interest.

6.2.4.1. Markov Reward Processes

In a joint work with I.M. H. Vliegen [Technische Universiteit Eindhoven, The Netherlands] and A. Scheller-Wolf [Carnegie Mellon University, USA] [45], we presented a new bounding method for Markov chains inspired by Markov reward theory: Our method constructs bounds by redirecting selected sets of transitions, facilitating an intuitive interpretation of the modifications of the original system. We show that our method is compatible with strong aggregation of Markov chains; thus we can obtain bounds for an initial chain by analyzing a much smaller chain. We illustrated our method by using it to prove monotonicity results and bounds for assemble-to-order systems.

In an ongoing work, we apply these results in an optimization problem of base stock levels for service tools inventory.

6.2.4.2. Censored Markov Chains.

Censored Markov chains (CMC) allow one to represent the conditional behavior of a system within a subset of observed states. They provide a theoretical framework to study the truncation of a discrete-time Markov chain when the generation of the state-space is too hard or when the number of states is too large. Unfortunately, the stochastic matrix of a CMC may be difficult to obtain. Dayar et al. (2006) have proposed an algorithm, called DPY, that computes a stochastic bounding matrix for a CMC with a smaller complexity with only a partial knowledge of the chain. In [29], we proved that this algorithm is optimal for the information they take into account. We also showed how some additional knowledge on the chain can improve stochastic bounds for CMC.

6.2.4.3. Iterative Bounds

In [30], [31] we proposed an iterative algorithm to compute component-wise bounds of the steady-state distribution of an irreducible and aperiodic Markov chain. These bounds are based on very simple properties of $(max, +)$ and $(min, +)$ sequences. We showed that, under some assumptions on the Markov chain, these bounds converge to the exact solution. In that case we have a clear tradeoff between computation and the tightness of bounds. Furthermore, at every step we know that the exact solution is within an interval, which provides a more effective convergence test than usual iterative methods.

6.2.5. Stochastic Stability

6.2.5.1. Bipartite Matching Queueing Model

In a joint work with V. Gupta [Carnegie Mellon University, USA] and J. Mairesse [LIAFA, CNRS and Université Paris 7] [43], we considered the bipartite matching queueing model of customers and servers introduced by Caldentey, Kaplan, and Weiss (Adv. Appl. Probab., 2009). Customers and servers play symmetrical roles. There is a finite set C, resp. S, of customer, resp. server, classes. Time is discrete and at each time step, one customer and one server arrive in the system according to a joint probability measure μ on $C \times S$, independently of the past. Also, at each time step, pairs of *matched* customer and server, if they exist, depart from the system. Authorized *matchings* are given by a fixed bipartite graph $(C, S, E \subset C \times S)$. A *matching policy* is chosen, which decides how to match when there are several possibilities. Customers/servers that cannot be matched are stored in a buffer.

The evolution of the model can be described by a discrete time Markov chain. We studied its stability under various admissible matching policies including: ML (Match the Longest), MS (Match the Shortest), FIFO (match the oldest), priorities. There exist natural necessary conditions for stability (independent of the matching policy) defining the maximal possible stability region. For some bipartite graphs, we prove that the stability region is indeed maximal for any admissible matching policy. For the ML policy, we proved that the stability region is maximal for any bipartite graph. For the MS and priority policies, we exhibited a bipartite graph with a non-maximal stability region.

6.2.5.2. Spatial Queues

In a joint work with S. Foss [Heriot–Watt University, UK] [54], we considered a queue where the server is the Euclidean space, the customers are random closed sets of the Euclidean space arriving according to a Poisson rain and where the discipline is a hard exclusion rule: no two intersecting random closed sets can be served at the same time. We use the max plus algebra and Lyapunov exponents to show that under first come first serve assumptions, this queue is stable for a sufficiently small arrival intensity. We also discuss the percolation properties of the stationary regime of the random closed sets in the queue.

6.2.6. Dynamics of Gossip in Random Networks

Gossip is a class of distributed linear algorithms which aim to reach a consensus on the average of the measurements of a wireless sensor network. The speed of convergence highly depends on the network topology, and unfortunately, in real-world topologies, these algorithms are slow. This year, we published a first paper [11] which mathematically solves the problem : Path Averaging averages random routes and is order $n \log n$ (optimal), but, as a counterpart, it is not very robust in dynamic networks. Indeed, to average a route, agents have to send data back and forth. We have then developed an algorithm, which converges correctly, which is fast on simulations, and which operates on random routes one way only. This algorithm thus recovers the robustness lost by Path Averaging. We called it Weighted Gossip [24]. Parallel to our work on weighted gossip we quantized regular gossip to obtain voting algorithms which are able to compute majority among 2, 3 or 4 candidates. The algorithms are asynchronous and use deterministic automata of 2 bits for the binary voting problem, 4 bits for the ternary voting problem and 7 bits for the quaternary voting problem. We wrote a paper in a special issue of signal processing about gossip algorithms, which was accepted under minor modifications.

6.3. Economics of Networks

Participants: François Baccelli, Marc Lelarge.

6.3.1. Diffusion and Cascading Behavior in Random Networks

The spread of new ideas, behaviors or technologies has been extensively studied using epidemic models. In [49], we considered a model of diffusion where the individuals' behavior is the result of a strategic choice. We studied a simple coordination game with binary choice and give a condition for a new action to become widespread in a random network. We also analyze the possible equilibria of this game and identify conditions for the coexistence of both strategies in large connected sets. Finally we look at how can firms use social networks to promote their goals with limited information.

Our results differ strongly from the one derived with epidemic models. In particular, we showed that connectivity plays an ambiguous role: while it allows the diffusion to spread, when the network is highly connected, the diffusion is also limited by high-degree nodes which are very stable. In the case of a sparse random network of interacting agents, we computed the contagion threshold for a general diffusion model and showed the existence of (continuous and discontinuous) phase transitions. We also computed the minimal size of a seed of new adopters in order to trigger a global cascade if these new adopters can only be sampled without any information on the graph. We showed that this minimal size has a non-trivial behavior as a function of the connectivity. Our analysis extends methods developed in the random graphs literature based on the properties of empirical distributions of independent random variables, and leads to simple proofs.

6.3.2. Economic Value of User Localization in Wireless Networks

The defining characteristic of wireless and mobile networking is user mobility, and related to it is the ability for the network to capture (at least partial) information on where users are located and how users change location over time. Information about location is becoming critical, and therefore valuable, for an increasingly larger number of location-based or location-aware services. A key open question, however, is how valuable exactly this information is. Our goal in this paper is to help understand and estimate the economics, or the value of location information.

In a joint work with J. Bolot [Sprint ATL, USA], [52], we addressed in particular the value of different granularities of location information, for example how much more valuable is it to know the GPS location of a mobile user compared to only knowing the access point, or the cell tower, that the user is associated with. We made three main contributions. First, we presented novel models, which capture the location-based economic activity of mobile users. Second, we derived closed-form analytic solutions for the economic value generated by those users. Third, we augmented the models to consider uncertainty about the users' location, and derived expressions for the economic value generated with different granularities of location information.

6.4. Point Processes, Stochastic Geometry and Random Geometric Graphs

Participants: François Baccelli, Bartłomiej Błaszczyszyn, Pierre Brémaud, Yogeshwaran Dhandapani, Mir Omid Haji Mirsadeghi, Justin Salez.

6.4.1. Stochastic Comparison of Random Measures and Point Processes

Stochastic geometric models (in particular these of wireless networks) are in general investigated in Poisson point process setting. Due to the difficulty (or even impossibility) of obtaining closed-form expressions for characteristics of these models in non-Poisson settings, we attempt a qualitative study of these characteristics, in particular by comparison to Poisson setting. *Directionally convex ordering* of point processes proved to be particularly pertinent in regard to this matter, as shown in [61]. This year we have continued working with this order, in particular using it to compare the clustering and percolation properties of point processes; cf. Section 6.4.2. The whole research axis was being developed in the PhD thesis [6] of D. Yogeshwaran defended in 2010.

6.4.2. Percolation and Directionally Convex Ordering

Comparisons of Ripley's functions and pair correlation functions seem to indicate that point processes higher in directionally convex (dcx) order cluster more. Simulation of various points processes comparable in this order, in particular in the class of the so called *perturbed lattice point processes*, also confirm this observation. These simulations, as well as some heuristics, indicate also that clustering of a point process negatively impacts the percolation of the related continuum percolation model, called also the Boolean model. We moved toward a formal statement of this heuristic. Namely, we defined two critical radii for percolation of the Boolean model called the lower and upper critical radii as these sandwich the usual critical radius for percolation of the Boolean model. We showed that dcx order preserves the upper critical radii and reverses the lower critical radii. Following this observation we considered a class of point processes, which we call *sub-Poisson*; these are point processes that can be dominated in dcx by some Poisson point process. For this class, we extended the classical result on the existence of phase transition in the percolation of the Gilbert's graph (called also the Boolean model, and in the historical result generated by a homogeneous Poisson point process). We also extended a recent result of the same nature for the SINR graph, to sub-Poisson point processes. This work is a part of the PhD thesis [6] of D. Yogeshwaran defended in 2010. Partial results have been presented at the Allerton Conference in 2010; cf [28], [48]. A more complete, journal paper [62] is under preparation.

6.4.3. Information Theory and Stochastic Geometry

In a joint work with V. Anantharam [UC Berkeley], [40], we studied the Shannon regime for the random displacement of stationary point processes. Let each point of some initial stationary point process in n-dimensional Euclidean space give rise to one daughter point, the location of which is obtained by adding a random vector to the coordinates of the mother point, with all displacement vectors independently and identically distributed for all points. The decoding problem is then the following one: the whole mother point process is known as well as the coordinates of some daughter point; the displacements are only known through their law; can one find the mother of this daughter point? The Shannon regime is that where the dimension n tends to infinity and where the logarithm of the intensity of the point process is proportional to n. We showed that this problem exhibits a sharp threshold: if the sum of the proportionality factor and of the differential entropy rate of the noise is positive, then the probability of finding the right mother point tends to 0 with n for all point processes and decoding strategies. If this sum is negative, there exist mother point processes, for instance Poisson, and decoding strategies, for instance maximum likelihood, for which the probability of finding the right mother tends to 1 with n. We then used large deviations theory to show that in the latter case, if the entropy spectrum of the noise satisfies a large deviation principle, then the error probability goes exponentially fast to 0 with an exponent that is given in closed form in terms of the rate function of the noise entropy spectrum. This was done for two classes of mother point processes: Poisson and Matérn. The practical interest to information theory comes from the explicit connection that we also establish between this problem and the estimation of error exponents in Shannon's additive noise channel with power constraints on the codewords.

6.4.4. Random Geometric Graphs

Random Geometric Graphs (RGG) have played an important role in providing a framework for modeling in wireless communication, starting with the pioneering work on connectivity by Gilbert (1961); [68]. Vertices or points of the graphs represent communicating entities such as base stations. These vertices are assumed to be distributed in space randomly according to some point process, typically a Poisson point process. En edge between two points means that the communicating entities able to communicate with each other. In the classical model an edge exists between any two pair of nodes if the distance between them is less than some critical threshold. A variant of this classical model that exhibits the union of the coverage regions of all nodes is also referred to in stochastic geometry as the Boolean model. In the following, more fundamental works, we studied some variants and extensions of the classical models, more or less related to wireless communication networks.

6.4.4.1. AB Random Geometric Graphs

We investigated percolation in the AB Poisson-Boolean model in d-dimensional Euclidean space, and asymptotic properties of AB random geometric graphs on Poisson points in $[0,1]^d$. The AB random geometric graph we studied is a generalization to the continuum of a bi-partite graph called the AB percolation model on discrete lattices. Such an extension is motivated by applications to secure communication networks and frequency division duplex networks. The AB Poisson Boolean model is defined as a bi-partite graph on two independent Poisson point processes of intensities λ and μ in the d-dimensional Euclidean space in the same manner as the usual Boolean model with a radius r. We showed existence of AB percolation for all $d \geq 2$, and derived bounds for a critical intensity. Further, in $d = 2$, we characterize a critical intensity. The set-up for AB random geometric graphs is to construct a bi-partite graph on two independent Poisson point process of intensities n and cnin the unit cube. We provided almost sure asymptotic bounds for the connectivity threshold for all $c > 0$ and a suitable choice of radius cut-off functions $r_n(c)$. Further for $c < c_0$, we derived a weak law result for the largest nearest neighbor radius. This work is a part of the PhD thesis [6] of D. Yogeshwaran defended in 2010. It has also been submitted for the publication as a research article [50].

6.4.4.2. Spatial percolation model for delay tolerant networks

Delay Tolerant Networks, in the simplest terms, are networks that take into account the time-delay at nodal points for the transmission of information in a network. First passage percolation models have been found to be useful for study of transmission of information along networks. We consider spatial growth models on stationary graphs constructed on point processes, similar in the spirit of continuum first passage percolation models. The dynamic governing this network model is the delayed propagation of the information at the vertices of the graph. Depending on the manner of the time-delay and information dissemination time, one can obtain various models. We are analyzing this class of models with the hope of obtaining shape theorem for the spread of information. These models combine the dynamics of both the first passage percolation models and Richardson growth models.

6.4.4.3. Optimal Paths on Space-Time SINR Graphs

In the context of the opportunistic routing described in Section 6.1.2.4, in a more fundamental paper [53] we studied optimal paths in wireless networks in terms of first passage percolation on some space-time SINR graph. We establish both "positive" and "negative" results on the associated the percolation delay rate (delay per unit of Euclidean distance called in the classical terminology time constant). The latter determines the asymptotics of the minimum delay required by a packet to progress from a source node to a destination node when the Euclidean distance between the two tends to infinity. The main negative result states that the percolation delay rate is infinite on the random graph associated with a Poisson point process under natural assumptions on the wireless channels. The main positive result states that when adding a periodic node infrastructure of arbitrarily small intensity to the Poisson point process, the percolation delay rate is positive and finite.

Finding optimal space-time paths studied above needs the knowledge of the future which is impossible in practice. So an interesting question consists in looking for local (both in time and space) algorithms. In [53] we proved the convergence of the radial routing under the SINR setup. Another work in progress consists in analyzing the directional algorithm. In this algorithm packet uses the best link in the desired direction as the next node.

6.4.5. Ergodicity of a Stress-Release-Point-Process Seismic Model with Aftershocks

The times of occurrence of earthquakes in a given area of seismic activity form a simple point process N on the real line, where $N((a,b])$ is the number of shocks in the time interval $(a,b]$. The dynamics governing the process can be expressed by the stochastic intensity $\lambda(t)$. In the stress release model, for $t \geq 0$, $\lambda(t) = e^{X_0 + ct - \sum_{n=1}^{N((0,t])} Z_n}$, where $c > 0$ and $\{Z_n\}_{n \geq 1}$ is an i.i.d. sequence of non-negative random variables with finite expectation, whereas X_0 is some real random variable. The process $X(t) = X_0 + ct - \sum_{n=1}^{N((0,t])} Z_n$ is known to be ergodic.

Another model of interest in seismology is the Hawkes branching process, where the stochastic intensity is $\lambda(t) = \nu(t) + \int_{(0,t]} h(t-s)N(ds)$, where h is a non-negative function, called the fertility rate and ν is a non-negative integrable function. Such point process appears in the specialized literature under the name ETAS (Epidemic Type After-Shock and is used to model the aftershocks. It is well known that the corresponding process “dies out” in finite time under the condition $\int_0^\infty h(t)\,dt < 1$.

A model mixing stress release and Hawkes aftershocks is

$$\lambda(t) = e^{X_0 + ct - \sum_{n=1}^{N((0,t])} Z_n} + Y_0 e^{-\alpha t} + k \int_{(0,t]} e^{-\alpha(t-s)}\, N(ds),$$

where $\alpha > 0$. The positive constant c is the rate at which the strain builds up. If there is a shock at time t, then the strain is relieved by the quantity $Z_{N(t)}$. Each shock (primary or secondary) at time t generates aftershocks according to a Poisson process of intensity $a(s) = ke^{-\alpha(t-s)}$. In [10], we gave necessary and sufficient conditions of ergodicity for this model.

6.5. Random Graphs and Combinatorial Optimization

Participants: Hamed Amini, Emilie Coupechoux, Mathieu Leconte, Marc Lelarge, Justin Salez.

6.5.1. Resolvent and rank of Large Random Graphs

In [9], with Charles Bordenave [CNRS, Toulouse], we analyzed the convergence of the spectrum of large random graphs to the spectrum of a limit infinite graph. We applied these results to graphs converging locally to trees and derive a new formula for the Stieljes transform of the spectral measure of such graphs. We illustrated our results on the uniform regular graphs, Erdős-Rényi graphs and preferential attachment graphs. We sketched examples of application for weighted graphs, bipartite graphs and the uniform spanning tree of n vertices.

In [41], we investigated the rank of the adjacency matrix of large diluted random graphs: for a sequence of graphs converging locally to a Galton-Watson tree, we provided an explicit formula for the asymptotic multiplicity of the eigenvalue 0 in terms of the degree generating function. In the first part, we showed that the adjacency operator associated with a Galton-Watson tree is self-adjoint with probability one ; we analyzed the associated spectral measure at the root and characterize the distribution of its atomic mass at 0. In the second part, we established a sufficient condition for the expectation of this atomic mass to be precisely the normalized limit of the dimension of the kernel of the adjacency matrices of the sequence of graphs. Our proofs borrow ideas from analysis of algorithms, functional analysis, random matrix theory, and statistical physics. This work has been presented at SODA [20].

6.5.2. Bootstrap Percolation in Random Networks

The bootstrap percolation model has been used in several related applications. In [7], we considered bootstrap percolation in living neural networks. Recent experimental studies of living neural networks reveal that global activation of neural networks induced by electrical stimulation can be explained using the concept of bootstrap percolation on a directed random network. The experiment consists in activating externally an initial random fraction of the neurons and observe the process of firing until its equilibrium. The final portion of neurons that are active depends in a non linear way on the initial fraction. Our main result in [7] is a theorem which enables us to find the final proportion of the fired neurons in the asymptotic case, in the case of random directed graphs with given node degrees as the model for interacting network.

6.5.3. Flooding in Weighted Random Graphs

In a joint work [51] with Moez Draief [Imperial College London], we studied the impact of the edge weights on distances in diluted random graphs. We interpret these weights as delays, and take them as i.i.d exponential random variables. We analyzed the edge flooding time defined as the minimum time needed to reach all nodes from one uniformly chosen node, and the edge diameter corresponding to the worst case edge flooding time. Under some regularity conditions on the degree sequence of the random graph, we showed that these quantities grow as the logarithm of n, when the size of the graph n tends to infinity. We also derived the exact value for the prefactors.

These allowed us to analyze an asynchronous randomized broadcast algorithm for random regular graphs. Our results show that the asynchronous version of the algorithm performs better than its synchronized version: in the large size limit of the graph, it will reach the whole network faster even if the local dynamics are similar on average.

6.5.4. Epidemics over Random Hypergraphs

In [65], we adapted the model given in [70], which is on graphs, to an equivalent on hypergraphs. For this, we generalized the result obtained by Darling and Norris in [66], which deals with the k-core of a random hypergraph. This allowed us to give an upper bound for the size of the giant component of random hypergraphs. We are now trying to adapt ideas from Janson and Luczak, in order to prove also a lower bound for this size. This would lead to the demonstration of a phase transition for the size of the largest component in random hypergraphs.

6.5.5. Matchings in infinite graphs

In [58], we proved that for any sequence of (deterministic or random) graphs converging locally, the corresponding sequence of normalized matching numbers converges, and this limit depends only on the limit of the graph sequence. In the particular case where this limit is a unimodular Galton Watson tree, we were able to compute explicitly the value for the limit of the sequence of (normalized) matching numbers. This leads to an explicit formula that considerably extends the well-known one by Karp and Sipser for Erdős-Rényi random graphs.

We considered a natural family of Gibbs distributions over matchings on a finite graph, parameterized by a single positive number called the temperature. The correlation decay technique can be applied for the analysis of matchings at positive temperature and allowed us to establish the weak convergence of the Gibbs marginal as the underlying graph converges locally. However for the zero temperature problem (i.e. maximum matchings), we showed that there is no correlation decay even in very simple cases. By using a complex temperature and a half-plane property due to Heilmann and Lieb, we were able to let the temperature tend to zero and obtained a limit theorem for the asymptotic size of a maximum matching in the graph sequence.

7. Contracts and Grants with Industry

7.1. ANR CMON

Participants: François Baccelli, Florence Bénézit, Bruno Kauffmann, Darryl Veitch.

TREC is a partner of the 3-year ANR project called CMON, jointly with Technicolor, LIP6, the INRIA project-team Planète and the community http://www.grenouille.com. This project is focused on the development of end-to-end measurement for Internet that can be deployed by end-users, without any support from ISP. A postdoc (F. Bénézit) was hired through this grant from year 2010 on. The main contribution of this year was the definition of the "Grenouille CohÃÂ©rente", a scheme allowing one to globally synchronize Grenouille client, jointly with A. Schmidt [Grenouille].

7.2. CIFRE Grant of Technicolor

Participants: Mathieu Leconte, Marc Lelarge.

The CIFRE grant of Mathieu starts in 2011 but started with an internship. The topic bears on information dissemination and recommendation in social networks. The distribution of multimedia content and the use of social networks like Facebook, Orkut, etc.. are booming in today's networks. These social networks are also increasingly used for dissemination and recommendation of content. Content distribution can then follow paths established by the network structure of social relations. The objective of the thesis will be to develop an understanding of how information disseminates in social networks based on the type of information, user tastes, and the topological structure of these networks. This study will result in developing methods for more effective dissemination of content.

7.3. Sprint ATL Grant

Participants: François Baccelli, Marc Lelarge.

In 2010, the interaction with the research lab of Sprint (Sprint ATL, in Burlingame, California) focused on two main topics:

- Bayesian inference to locate mobiles in cellular networks [39].
- The analysis of the economics of communication networks [52].

This collaboration resulted in several joint papers this year again.

7.4. Scientific partnership with EADS CCR

Participants: François Baccelli, Bartłomiej Błaszczyszyn, Yogeshwaran Dhandapani.

A 6 year Scientific partnership "Action de Partenariat Informatique Fondamentale" between ENS and EADS CC started in September 06. This action allowed TREC to hire in 2007 a PhD student, D. Yogeshwaran from IISc Bangalore. This thesis bears on the stochastic comparison of random measures, point process and shot-noise fields; cf. Section 6.4.1. It was successfully defended in November 2010; cf [6].

7.5. CRE with FT: "How the Shadowing Impacts the Quality of Service in Wireless Cellular Networks"

Participants: Bartłomiej Błaszczyszyn, François-Xavier Klepper.

Trec realized in 2010 a research contract number CRE 46146063-A012 between INRIA and France Télécom. The objective was to study the impact of the shadowing on the quality of service perceived by the users in wireless cellular networks. Partial results were presented at the IFIP WMNC'10 Conference [25]. A more complete journal paper [60] is under preparation. For more details see Section 6.1.1.1. F.-X. Klepper was hired by Inria as a research engineer within this contract.

7.6. ANR PEGASE

Participants: Anne Bouillard, Nadir Farhi.

TREC is a partner of the 3-year ANR project called PEGASE, jointly with ENS Lyon, the INRIA project-team MESCAL, ONERA, Real-Time-at-Work (start-up) and Thalès. This project is focused on the analysis of critical embedded networks using algebraic tools. The aim is to apply these techniques to AFDX and Spacewire architectures. A post-doc (N. Farhi) has been hired through this grant in September 2010.

7.7. ANR MAGNUM

Participant: Ana Bušić.

Ana Bušć is participating (20%) in the ANR project MAGNUM (Méthodes Algorithmiques pour la Génération aléatoire Non Uniforme: Modèles et applications), November 2010 – 2014; http://www-apr.lip6.fr/anrMagnum/.

8. Other Grants and Activities

8.1. Networks and International Working Groups

- TREC is a partner of the *European Network of Excellence (NoE)* Euro-NF http://euronf.enst.fr/en_accueil.html. This NoE, which is focused on the next generation Internet, is led by Groupement des Ecoles de Télécoms (GET) and has about 30 partners. This year B. Błaszczyszyn gave a tutorial course (3h) on “Stochastic geometry and wireless networks” at the 3rd Euro-NF Summer School on Opportunistic Networking, Valencia (Spain), June/July 2010; http://euronf.enst.fr/p_en_Events_Events2010_Summerscho_420.html and http://www.girba.upv.es/summerschool/.
- F. Baccelli was co-organizer of the 6 month program entitled “Stochastic Processes and Communication Sciences” at the **Isaac Newton Institute for Mathematical Sciences**, Cambridge, UK. This programme aimed at the exposition of the latest developments in mathematical sciences lying on the boundary between the disciplines of stochastics and communications. It brought together experts in the fields of probability and communications in order to review and further develop knowledge and trends. Probability theory and communications have developed hand in hand for about a century. The research challenges in the latter field (from telephone networks to wireless communications and the Internet) have spurred the development of the mathematical theory of stochastic processes, particularly in the theory of Markov processes, point processes, stochastic networks, stochastic geometry, stochastic calculus, information theory, and ergodic theory to name but a few. Conversely, a large number of applications in communications would not have been possible without the development of stochastics. The programme was attended by 87 long-term participants and 23 short-stay ones, several of which were young researchers or graduate students. It also hosted several workshops and special events in the following areas: An inaugural workshop on the interface between Probability and Communications which explored probabilistic methods (e.g. Information Theory) for communication systems http://www.newton.ac.uk/programmes/SCS/scsw01.html. A workshop on stochastic networks which was planned to cover traditional and new aspects of the field, ranging from performance analysis of queueing and communication networks to new applications in biological and chemical networks http://www.newton.ac.uk/programmes/SCS/scsw02.html. A workshop on spatial networks which presented methods based on stochastic geometry, random graphs, percolation, and random matrix theory, with particular emphasis on applications to wireless networks http://www.newton.ac.uk/programmes/SCS/scsw03.html. A workshop on simulation of networks, focusing on the stochastic simulation of complex networks via Monte Carlo and newer approaches, such as particle methods http://www.newton.ac.uk/programmes/SCS/scsw05.html. A workshop on the statistics of networks the intention of which was to understand data collection and analysis in networks and their further use in building mathematical models http://www.newton.ac.uk/programmes/SCS/scsw08.html. Two special events were also organized: The first one was a one-day open for business event on communication architecture for the future. The second one was the energy systems week, a special programme organized around the new relations between networks and power

systems. Special emphasis was placed on young researchers and students throughout the programme. This culminated with the satellite workshop for young researchers which took place in Edinburgh which was co-organized by Marc lelarge.

9. Dissemination

9.1. Animation of the Scientific Community

9.1.1. TREC's seminar

The following scientists gave talks in 2010:

- France
  - Vlady Ravelomanana (LIAFA) talking on "Random Bipartiteness, 2-XOR-SAT, MAX-2-XOR-SAT and MAX-CUT"; December 2010,
  - D. Yogeshwaran (ENS/INRIA), PhD thesis defense talking on "Stochastic geometric networks : Connectivity and comparison"; November 2010,
  - Amar Prakash Azad (INRIA Sophia Antipolis) talking on "Combined Optimal Control of Activation and Transmission in Delay Tolerant Networks"; November 2010,
  - Thach Nguyen (LIAFA) talking on "Deficiency zero Petri nets"; November 2010,
  - Emmanuel Hyon (Université Paris Ouest, France) talking on "Scheduling in a Queuing System with Impatience and Setup Costs"; July 2010,
  - Justin Salez (ENS, France) talking on "Matchings on diluted graphs : the cavity method at positive temperatures"; June 2010,
  - Mohamed Karray (Orange Labs, France) talking on "Fading Effect on the Dynamic Performance Evaluation of OFDMA Cellular Networks"; June 2010,
  - Djalil Chafai (Université Paris-Est Marne-la-Vallée, France) talking on "Vitesse de convergence de processus markoviens déterministes par morceaux"; April 2010,
- Europe
  - Alexander Rybko (IPIT, Moscow) talking on "Poisson Hypothesis for Infinite Generalized Jackson Networks"; November 2010,
  - Nikolaos Fountoulakis (MPII) talking on "The push algorithm for broadcasting and the geometry of graphs"; November 2010,
  - Daniel Gentner (Univ. of Karlsruhe) talking on "Inspecting partially stationary models in Stochastic Geometry: Palm Theory and Mass-Transport Principle"; October 2010,
  - Mathew Penrose (Univ. of Bath) talking on "Percolation and limit theory for the Poisson lilypond model"; September 2010,
  - Ruediger Urbanke (EPFL, Suisse) talking on "Spatially Coupled Codes — A New Paradigm for Code Design"; July 2010,
  - Vijay G. Subramanian (Hamilton Institut, Ireland) talking on "Large Deviations of Max-Weight Scheduling Policies"; March 2010,
- Asia, Australia, Canada, USA
  - George Stacey Staples (Southern Illinois University Edwardsville) talking on "Wireless Networks and Random Graphs: An Operator Calculus Approach"; November 2010,
  - Kenneth Shum (Chinese University of Hong Kong) talking on "The repair problem in distributed storage system"; September 2010,
  - Anant Sahai (U.C. Berkeley) talking on "Challenges for spectrum sharing by cognitive radios"; September 2010,
  - David Gamarnik (MIT, US) talking on "Statistical physics, interpolation method and scaling limits in sparse random graphs"; April 2010.

9.1.2. Miscellaneous

- TREC is a founding member of and participates to Paris-Networking (http://www.paris-networking.org/), a virtual community of researchers in networking who work in or around Paris (or visit Paris).
- A. Bušić animates the project-team seminar http://www.di.ens.fr/~trec/.
- M. Lelarge animates the reading group on mixing time; http://www.di.ens.fr/~lelarge/gdl.html and the working seminar on graphs, algorithms and probabilities; http://www.di.ens.fr/~lelarge/gap.html
- B. Błaszczyszyn is a member of *Commission détachement, délégation et post-doc "sur subvention", Inria Rocquencourt*.
- P. Brémaud is a member of the editorial board of the following journals: *Journal of Applied Probability, Advances in 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, Advances in Applied Probability*.

9.2. University Teaching

University of Pierre and Marie Curie, Paris 6

- Graduate Course on point processes, stochastic geometry and random graphs (program "Master de Sciences et Technologies"), B. Błaszczyszyn and L. Massoulié (45h).
- Undergraduate course LI325 (Algorithms and applications) by Ana Bušić (30h).
- "Graph Theory and Combinatorics" at Université Paris 6, J. Salez (January to June, 2010),

Ecole Normale Supérieure

- Undergraduate course (master level, MMFAI) by F. Baccelli, A. Bouillard and P. Brémaud, on Random Structures and Algorithms (35h + 28h of exercise session).
- Undergraduate exercise session (master level, MMFAI) by A. Bouillard on formal languages, computability and complexity.
- Course on Information Theory and Coding (master level, MMFAI) by M. Lelarge (26h) and exercise sessions (26h) by J. Salez.
- Course on Communication Networks (master level, MMFAI) by F. Baccelli and A. Chaintreau (24h).

Ecole Polytechnique Fédérale de Lausanne Stochastic Models in Communications and Computer Science (graduate course), F. Bénézit (70h).

Classes Préparatoires

- Course on "Formal Calculus" in Lycée Henri IV, J. Salez (January to June, 2010),

Tutorials

- "Stochastic geometry and wireless networks" at the 3rd Euro-NF Summer School on Opportunistic Networking, Valencia (Spain), June/July 2010, http://euronf.enst.fr/p_en_Events_Events2010_Summerscho_420.html and http://www.girba.upv.es/summerschool/.

9.3. Invitations and Participation in Conferences

Hamed Amini

- Visiting Max-Planck-Institut, Saarbrücken, Germany, September 2010,

- Presentation in the following conferences or seminars:
  - Max-Planck-Institut, Saarbrücken, Germany, September 2010; http://www.mpi-inf.mpg.de,
  - Bachelier congress, Toronto, Canada, June 2010; http://www.bfs2010.com,
- Participation in the following conferences:
  - Spatial Network Models for Wireless Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, April 2010; http://www.newton.ac.uk/programmes/SCS/scsw03.html.

François Baccelli

- Member of
  - the program committee of IEEE Infocom 2011, Spaswin 2010;
  - the NWO international committee for the evaluation of the Dutch Mathematical Clusters (Nov. 2010);
  - the scientific board of the Alcatel/Lucent–INRIA Joint Laboratory (since 2008);
  - the IFIP working group WG 7.3.
- Honorary Professor at Heriot Watt University.
- Reviewer of the thesis of R. Lachieze-Rey (Université de Lille), S. Lasaulce (L2S, habilitation) and N. Schabanel (Liafa, habilitation).
- Author of a survey article on the future of communication network for Annales des Mines [15].
- Presentation in the following conferences or seminars:
  - NSF Workshop on the Frontiers of Controls, Games and Network Science, February 19 - 20, 2010, Austin, UT Austin; http://wncg.org/NETSCI-Workshop/ (invited lecture);
  - Ecole Polytechnique, Febr. 2010 (CINE lecture);
  - Conseil scientifique de l'INRIA, Febr. 2010;
  - Stochastic Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, March 2010; http://www.newton.ac.uk/programmes/SCS/scsw02.html (invited lecture);
  - INSA Lyon, April 2010;
  - Technicolor seminar, April 2010;
  - Princeton University, May 2010;
  - Qualcomm Research, May 2010;
  - Bristol University, June 2010;
  - 9th Workshop on stochastic analysis and related fields, a conference in honor of A.S. Üstünel for his 60th birthday, Telecom ParisTech, Paris, Sept. 2010. http://www.infres.enst.fr/wp/mic2/2009/12/24/9th-workshop-on-stochastic-analysis-and-related-fields/.
  - 2nd IFAC Workshop on Distributed Estimation and Control in Networked Systems, NECSYS'10, Annecy, Sept. 2010 http://necsys2010.inrialpes.fr/ (keynote lecture).

Florence Bénézit

- Presentation in the following conferences or seminars:
  * International Sgymposium on Information Theory (ISIT), Austin, USA, June 2010; http://www.isit2010.org/.

Bartłomiej Błaszczyszyn

- Presentation in the following conferences or seminars:
  * IEEE Infocom 2010, San Diego, CA, USA, March 2010; http://www.ieee-infocom.org/2010/index.html,
  * Spatial Network Models for Wireless Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences , Cambridge, UK, April 2010; http://www.newton.ac.uk/programmes/SCS/scsw03.html.
  * Workshop on Stochastic Processes in Communication Networks for Young Researchers, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Edinburgh, UK, June 2010; http://www.icms.org.uk/workshops/stocpro,
  * Tutorial at the 3rd Euro-NF Summer School on Opportunistic Networking, Valencia (Spain), June/July 2010; http://euronf.enst.fr/p_en_Events_Events2010_Summerscho_420.html and http://www.girba.upv.es/summerschool/.
  * Third Joint IFIP Wireless and Mobile Networking Conference (IFIP WMNC) October 2010, Budapest, Hungary; http://regi.kvk.uni-obuda.hu/wmnc2010/.
- Participation in the following conferences:
  * Workshop on New Topics at the Interface Between Probability and Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, GB, January 2010; http://www.newton.ac.uk/programmes/SCS/scsw01.html.
  * Mathematical Challenges in Stochastic Networks, Oberwolfach, October 2010; http://www.mfo.de/cgi-bin/tagung_espe?type=21&tnr=1042,

Anne Bouillard

- Presentation in the following conferences or seminars:
  * 10th International Workshop on Discrete Event System (WODES), Berlin, August/September 2010; http://ti3.ee.tu-berlin.de/bigace2/,
  * 10th International Conference on Embedded Software (EMSOFT), Scottdaloe, Arizona, October 2010; http://ptolemy.eecs.berkeley.edu/conferences/10/emsoft10/.

Ana Bušić

- Presentation in the following conferences or seminars:
  * Poster presentation at Stochastic Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, March 2010; http://www.newton.ac.uk/programmes/SCS/scsw02.html,
  * Poster presentation at Simulation of Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, June 2010; http://www.newton.ac.uk/programmes/SCS/scsw05.html,

    - Workshop on Stochastic Processes in Communication Networks for Young Researchers, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Edinburgh, UK, June 2010; http://www.icms.org.uk/workshops/stocpro,
    - QEST 2010 and NSMC 2010, Williamsburg, Virginia, USA, September, 2010; http://www.qest.org/qest2010/, http://www.cs.bilkent.edu.tr/~nsmc10/.
- Participation in the following conferences:
    - Dynamics and Computation, 2nd week of "Math-Info 2010 Towards new interactions between mathematics and computer science", C.I.R.M, Marseille, February 2010; http://www.lirmm.fr/arith/wiki/MathInfo2010/DynamicsAndComputation,
    - Spatial Network Models for Wireless Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, April 2010; http://www.newton.ac.uk/programmes/SCS/scsw03.html.
    - MAMA 2010 (workshop of SIGMETRICS), June 2010; http://www.sigmetrics.org/sigmetrics2010/mama_schedule.shtml,
    - JAC 2010, Turku, Finland, December 2010; http://www.math.utu.fi/projects/jac2010/.

Chung-Shue Chen

- Member of the program committee of IEEE WCNC'10, CCNC'10.
- Presentation in the following conferences or seminars:
    - INRIA Alcatel-Lucent Joint Lab seminar, Villarceaux, France, March 2010,
    - IEEE International Conference on Communications (ICC'10), Cape Town, South Africa, May 2010; http://www.ieee-icc.org/2010,
    - Alcatel-Lucent Bell Labs Open Days 2010, Villarceaux, France, May 2010,
    - INRIA Alcatel-Lucent Selfnet seminar, Paris, France, November 2010.

Emilie Coupechoux

- Presentation in the following conferences or seminars:
    - Aléa, Marseille, March 2010; http://www-apr.lip6.fr/alea2010/index.php
    - Seminar "Combinatoire énumérative et analytique", Paris (LIAFA), October 2010; http://www.liafa.jussieu.fr/web9/manifsem/listmanif_fr.php?anscol=10-11&typecongres=9

Bruno Kauffmann

- Presentation in the following conferences or seminars:
    - Poster presentation at Statistics of Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, June 2010; http://www.newton.ac.uk/programmes/SCS/scsw08.html
- Participation in the following conferences:
    - Simulation of Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, June 2010; http://www.newton.ac.uk/programmes/SCS/scsw05.html

Marc Lelarge

- Organization with D. Denisov and B. Zwart of Workshop on Stochastic Processes in Communication Networks for Young Researchers, Edinburgh, June 2010; http://www.icms.org.uk/workshops/stocpro.
- Presentation in the following conferences or seminars:
  * ACM-SIAM Symposium on Discrete Algorithms (SODA10), Autin, January 2010; http://www.siam.org/meetings/da10/
  * 2010 Information Theory and Applications Workshop (ITA 2010), San Diego, February 2010; http://ita.ucsd.edu/workshop.php
  * Stochastic Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, March 2011; http://www.newton.ac.uk/programmes/SCS/scsw02.html
  * International Workshop in Applied Probability (IWAP 2010), Madrid, July 2010; http://www.fundacion.uc3m.es/IWAP2010/
  * Journées MAS, Bordeaux, September 2010; http://www.math.u-bordeaux1.fr/MAS10/
  * Mathematical Challenges in Stochastic Networks, Oberwolfach, October 2010; http://www.mfo.de/cgi-bin/tagung_espe?type=21&tnr=1042,
  * Fourth EPFL-UPEMLV Workshop on Random Matrices, Information Theory and Applications, Paris, December 2010; http://ipg.epfl.ch/~leveque/EPFL_UPEMLV_Workshop/.
- Participation in the following conferences:
  * New Topics at the Interface Between Probability and Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, January 2011; http://www.newton.ac.uk/programmes/SCS/scsw01.html.

Mir Omid Haji Mirsadeghi

- Participation in the following conferences:
  * Stochastic Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, March 2010; http://www.newton.ac.uk/programmes/SCS/scsw02.html
  * Spatial Network Models for Wireless Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, April 2010; http://www.newton.ac.uk/programmes/SCS/scsw03.html
  * Stochastic Processes in Communication Networks for Young Researchers, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Edinburgh, UK, June 2010; http://www.icms.org.uk/workshops/stocpro
  * Simulation of Networks Workshop, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, June 2010; http://www.newton.ac.uk/programmes/SCS/scsw05.html

  * Statistics of Networks Workshop, in the programme “Stochastic Processes in Communication Sciences”, Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, June 2010; http://www.newton.ac.uk/programmes/SCS/scsw08.html

Frédéric Morlot

- Presentation in the following conferences or seminars:
  * IEEE Infocom 2010, San Diego, CA, USA, March 2010; http://www.ieee-infocom.org/2010/index.html

Tien Viet Nguyen

- Presentation in the following conferences or seminars:
  * 2010 IEEE Symposium on New Frontiers in Dynamic Spectrum (DYSPAN10), Singapore, 04/2010; http://www.ieee-dyspan.org/2010/.
- Participation in the following conferences:
  * Stochastic Networks Workshop, in the programme “Stochastic Processes in Communication Sciences”, Isaac Newton Institute for Mathematical Sciences, Cambridge, http://www.newton.ac.uk/programmes/SCS/scsw02.html.

Van Minh Nguyen

- Member of the program committee of the IEEE ICC Cognitive Radio and Networks Symposium 2010.
- Presentation in the following conferences or seminars:
  * Sixth International Workshop on Spatial Stochastic Models for Wireless Networks (SpasWIN), Avignon, France, June 2010; http://www.spaswin.org/2010/,
  * Bell Labs, Fraunhofer Heinrich Hertz Institute and Deutsche Telekom Labs’ joint workshop of on the *Future of Communications: Science, Technologies, and Services*, Berlin, June 2010; http://cso.research.bell-labs.com/FCSTS/,
  * IEEE 21st International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Istanbul, Turkey, Sept 2010; http://www.ieee-pimrc.org/2010/index.html,

Justin Salez

- Presentation in the following conferences or seminars:
  * Workshop on Statistical Physics of Complexity, Optimization and Systems Biology, Ecole de Physique des Houches, Marsh 2010; http://houches.ujf-grenoble.fr
  * 8^{th} French Combinatorial Conference, Orsay, June 2010; http://8fcc.lri.fr
  * Journées Modélisation Aléatoire et Statistique, Bordeaux, September 2010; http://www.math.u-bordeaux1.fr/MAS10/index.html
  * Workshop on Mathematical Challenges in Stochastic Networks, Oberwolfach, October 2010; http://www.mfo.de
  * Fourth EPFL-UPEMLV Workshop on Random Matrices, Information Theory and Applications, Paris, December 2010; http://ipg.epfl.ch/~leveque/EPFL_UPEMLV_Workshop

Darryl Veitch

- Member of the program committee of ACM Sigmetrics 2010.
- Presentation in the following conferences or seminars:

    * OSDI, Vancouver, October, 2010; http://www.usenix.org/events/osdi10/.
  - Participation in the following conferences:
    * ACM Internet Measurement Conference, Melbourne, 2010; http://conferences.sigcomm.org/imc/2010/.

Yogeshwaran Dhandapani

  - Presentation in the following conferences or seminars:
    * Poster presentation at Spatial Network Models for Wireless Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, April 2010; http://www.newton.ac.uk/programmes/SCS/scsw03.html.
    * Workshop on Stochastic Processes in Communication Networks for Young Researchers, Edinburgh, UK. June 2010; http://www.icms.org.uk/workshops/stocpro ;
    * ICM Satellite Conference on Probability and Stochastic Processes, Bangalore, India. August 2010 http://www.isibang.ac.in/~statmath/icmprobsat/;
    * Departement of Mathematics, Indian Institute of Technology-Madras, Chennai, India. August 2010 ;
    * The 48th Allerton Conference in Communication, Control and Computing, Urbana-Champaign, USA. September 2010 http://www.csl.illinois.edu/allerton/;
  - Participation in the following conferences:
    * New Topics at the Interface Between Probability and Communications, in the programme "Stochastic Processes in Communication Sciences", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK. January 2010; http://www.newton.ac.uk/programmes/SCS/scsw01.html.

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Major publications by the team in recent years

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[2] F. BACCELLI, B. BŁASZCZYSZYN. *Stochastic Geometry and Wireless Networks, Volume II — Applications*, Foundations and Trends in Networking, NoW Publishers, 2009, vol. 4, No 1–2, http://hal.inria.fr/inria-00403040.

[3] P. BRÉMAUD. *Point Processes and Queues: Martingale Dynamics*, Springer-Verlag, 2005.

[4] P. BRÉMAUD. *Initiation aux Probabilites et aux chaines de Markov*, Springer-Verlag, 2009.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[5] P. BERMOLEN. *Modèles Probabilistes et Statistiques pour la Conception et l'Analyse des Systèmes de Communications*, Télécom ParisTech, France, February 2010.

[6] D. YOGESHWARAN. *Stochastic geometric networks : connectivity and comparison*, Université Pierre et Marie Curie, Paris, France., 2010, http://tel.archives-ouvertes.fr/tel-00541054.

Articles in International Peer-Reviewed Journal

[7] H. AMINI. *Bootstrap percolation in living neural networks*, in "Journal of Statistical Physics", 2010, vol. 141, p. 459–475.

[8] F. BACCELLI, B. BŁASZCZYSZYN, P. MÜHLETHALER. *Time-Space Opportunistic Routing in Wireless Ad Hoc Networks, Algorithms and Performance*, in "The Computer Journal", 2010, vol. 53, n^o 5, p. 592–609, Advance Access published on June 12, 2009, http://dx.doi.org/10.1093/comjnl/bxp049, http://hal.inria.fr/inria-00380642.

[9] C. BORDENAVE, M. LELARGE. *Resolvent of large random graphs*, in "Random Struct. Algorithms", 2010, vol. 37, n^o 3, p. 332–352, http://dx.doi.org/10.1002/rsa.20313.

[10] P. BRÉMAUD, S. FOSS. *Ergodicity of a stress release point process seismic model with aftershocks*, in "Markov Processes and Related Fields", 2010, vol. 16, n^o 2, p. 389–408.

[11] F. BÉNÉZIT, DIMAKIS, ALEXANDROS, G., P. THIRAN, M. VETTERLI. *Order-Optimal Consensus Through Randomized Path Averaging*, in "IEEE Trans. on Information Theory", 2010, vol. 56, n^o 10, http://dx.doi.org/10.1109/TIT.2010.2060050.

[12] VAN MINH. NGUYEN, F. BACCELLI, L. THOMAS, CHUNG SHUE. CHEN. *Best signal quality in cellular networks: asymptotic properties and applications to mobility management in small cell networks*, in "EURASIP Journal on Wireless Communications and Networking", 2010, vol. 2010, p. 1–14, http://dx.doi.org/10.1155/2010/690161.

[13] F. PIN, D. VEITCH, B. KAUFFMANN. *Statistical estimation of delays in a multicast tree using accelerated EM*, in "Queueing Systems", 2010, vol. 66, p. 369–412, http://dx.doi.org/10.1007/s11134-010-9195-9.

[14] K. SHUM, W. S. WONG, CHUNG SHUE. CHEN. *A general upper bound on the size of constant-weight conflict-avoiding codes*, in "IEEE Transactions on Information Theory", 2010, vol. 56, n^o 7, p. 3265–3276.

Articles in National Peer-Reviewed Journal

[15] F. BACCELLI. *Les réseaux de communication du futur*, in "Annales des Mines", November 2010, p. 5–9.

International Peer-Reviewed Conference/Proceedings

[16] J. ANDREWS, F. BACCELLI, R. GANTI. *A Tractable Approach to Cellular Network Modeling*, in "The 48th Allerton conference on communication, control and computing", University of Illinois at Urbana-Champaign, 2010.

[17] F. BACCELLI, B. BŁASZCZYSZYN. *A New Phase Transition for Local Delays in MANETs*, in "Proc. of IEEE INFOCOM", San Diego CA, 2010, http://dx.doi.org/10.1109/INFCOM.2010.5462132, http://hal.inria.fr/inria-00435237.

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