INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Trec

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Activity Report

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TREC is a joint INRIA-ENS project-team.

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2. Overall Objectives

2.1. Overall Objectives

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

- communication network control: admission control, flow regulation, congestion control, traffic analysis in controlled networks;
- modeling and performance analysis of wireless networks (cellular, mesh, ad-hoc, sensor, etc.): coverage and load analysis, power control, evaluation and optimization of the transport capacity, self organization;
- stochastic network dynamics, in particular by means of algebraic methods, with a main emphasis on rare events and large network asymptotics; economics of networks; a new domain opened in 2008: 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.
- combinatorial optimization and analysis of algorithms: random graphs, belief propagation.

3. Scientific Foundations

3.1. Scientific Foundations

Here is the scientific content of each of our main research directions.

- Modeling and control of communication networks. Here we mean control of admission, flow regulation and feedback control *à la TCP*, the understanding and improvements of which are major challenges within the context of large networks. Our aim is a mathematical representation of the dynamics of the most commonly used control protocols, from which one could predict and optimize the resulting end user bandwidth sharing and QoS. We currently try to use our better understanding of the dynamics of these protocols on Split TCP as used in wireless access networks and in peer-to-peer overlays.
- Modeling and performance analysis of wireless networks. The main focus is on the following three classes of wireless networks: cellular networks, mobile ad hoc networks (MANETs) and WiFi mesh networks.

  Concerning cellular networks, our mathematical representation of interferences based on shot-noise has led to a variety of results on coverage and capacity of large CDMA networks when taking into account intercell interferences and power control. Our general goal is to propose a strategy for the densification and parameterization of UMTS and future OFDM networks that is optimized for both voice and data traffic.

  Using a similar approach, in particular additive and extremal shot-noise processes, we currently investigate also MAC layer scheduling algorithms and power control protocols for MANETs and their vehicular variants called VANETs. We concentrate on cross layer optimizations allowing one to maximize the transport capacity for multihop MANETs. A recent example within this class of problems is the concept of opportunistic routing for MANETs that we currently study with the Hipercom project team of Rocquencourt.

  We also continue the line of thoughts on the self-organization of WiFi mesh networks. The general problem within this context is to find robust and fully distributed algorithms for the selection of channels by access points, for the association of users to access points, for the power used by access points, and for routing in mesh networks. We proposed and analyzed new classes of algorithms based on Gibbs' sampler.
- Theory of network dynamics. TREC is also pursuing the elaboration of a stochastic network calculus, that would allow the analysis of network dynamics by algebraic methods. The mathematical tools are those of discrete event dynamical systems: semi-rings (max, plus) and inf-convolutions, as well as their non linear extensions (topical and non expansive maps, monotone separable framework); the main probabilistic tools within this framework are ergodic theory, asymptotic analysis, Lyapounov exponent analysis, perturbation analysis and large deviations. The main current contributions bear on the analysis of rare events within this framework.
- Economics of networks We started this new direction of research with Jean Bolot (SPRINT). The premise of the research 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 incentives are missing for improved security measures. We then analyzed the possible impact of insurance.
- The development of mathematical tools based on stochastic geometry and random geometic graphs Classical Stochastic Geometry. 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. Initially its development was stimulated by applications to biology, astronomy and material sciences. Nowadays it is also

widely used in image analysis. Fundamentally, Stochastic Geometry provides a way of estimating and computing spatial averages. A typical example, with obvious communication implications, is the so called Boolean model, which is defined as the union of discs with random radii (communication ranges), centered at the points of a Poisson point process (the random user locations) of the Euclidean plane (e.g a large city). A first typical question is that of the prediction of the fraction of the plane which is covered by this union (statistics of coverage). A second one is whether this union has an infinite component or not (connectivity). This research domain 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 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 assignement problem and to characterize its performance. Likewise, we made a sensitivity analysis of such processes and computed the corresponding scaling exponents (for the minimal spanning tree problem and a dynamic programming optimization problem).

4. Application Domains

4.1. Application Domains

Depending on the classes of communication networks, we focus on different issues:

- Concerning the Internet, we concentrate on Internet probing.
- Concerning operator networks, we work on the control and the optimization of both wireless cellular networks and wireline access networks;
- Concerning self-organized networks, we focus on the design of MAC and routing protocols and on the evaluation of the capacity.

We interact on these questions with the following industrial partners: Thomson (self organized networks), Alcatel (wireline access) and Sprint (Internet probing and wireless access). We also have some point to point interactions with researchers of France Télécom on wireless cellular networks.

5. Software

5.1. SERT

Keywords: *admission control*, *blocking*, *capacity*, *cdma*, *outage*.

Participants: François Baccelli, Bartek Błaszczyszyn, Mohamed Karray [FT R&D].

The SERT (Spatial Erlang for Real Time services) Software was designed by M. Karray 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 FT R&D described in Section 6.2.1. This software is now part of the dimensioning tools used by Orange for its UMTS network. This year, the main focus of SERT was on the streaming traffic service.

6. New Results

6.1. Analysis and Optimization of Flow-Control Protocols

Keywords: *AQM*, *IP networks*, *TCP*, *congestion prevention/control additive increase multiplicative*, *decrease algorithm*, *feedback control*, *flow model*, *multicast*, *stability*.

Participants: François Baccelli, Giovanna Carofiglio.

Operators require a methodology for analyzing Internet traffic and control protocols to do resource planning (buffer capacities and bandwidth) capable of handling every possible mix of traffic (voice, video and data) with predefined end to end QoS. The main topics covered in 2008 are the analysis of a fast TCP variant called Scalable TCP, that of non persistent TCP flows (such as HTTP flows) and that of Split TCP (as used in some wireless and some peer to peer networks).

6.1.1. PDEs for TCP Flows

In [39], a general solution for the class of transport equations that arise within the context of both persistent and non persistent TCP flows was derived. This class contains two cases of loss point process models: the rate-independent Poisson case where the packet loss rate is independent of the throughput of the flow and the rate-dependent case where the point process of losses has an intensity which is a function of the instantaneous rate. We also gave a direct proof of the fact that there is a unique density solving the associated differential equation and we provide a closed form expression for this density and for its mean value.

In [9], we addressed the evaluation of the stationary distribution of a single HTTP flow which alternates between ON and OFF times; an OFF period consists in the transmission of a file with a random size. Each transmission is regulated by an additive increase, multiplicative decrease protocol. Both the rate dependent and rate independent cases were considered.

In [17] and in the PhD thesis [6] of G. Carofiglio this framework was extended to the family of MIMD algorithms, with particular attention devoted to Scalable TCP. Under the assumption of rate-dependent Poisson losses, the evolution of the TCP rate was studied through stochastic differential equations (SDEs) and, correspondingly, partial differential equations (PDEs) were derived for the rate distribution, analytically solved in steady state via Mellin transforms.

6.1.2. Split TCP

TCP was mainly developed for wired reliable links, where packet losses occur mostly because of congestion. In wireless networks, performance problems arise as TCP often over-reacts to losses due to radio transmission errors. The split-connection approach is an overlay structure that has has been adopted to cope with this problem. Initially proposed in the context of wireless networks, the “split connection” approach has been adopted in satellite networks and overlay networks of different nature: peer to peer systems, content delivery networks to cite a few examples. The idea of Split TCP is to replace a multihop, end-to-end TCP connection by a cascade of shorter TCP connections using intermediate nodes as proxies, thus achieving higher throughput. In the model that we developed with S. Foss we considered two long-lived TCP-Reno flows traversing two links with different medium characteristics in cascade. A buffer at the end of the first link will prevent the loss of packets that cannot be immediately forwarded on the second link by storing them temporarily. The target of our study is the characterization of the TCP throughput on both links as well as the buffer occupancy. In our work we made the following analytical contributions: we established the equations for throughput dynamics jointly with that of buffer occupancy in the proxy. We then determined the stability conditions by exploiting some intrinsic monotonicity and continuity properties of the system. Finally, we focused on the study of buffer occupancy in the proxy and end-to-end delays to derive tail asymptotics. The framework allowed us to consider both the case with an infinite buffer at the proxy and that of a limited buffer size, where a backpressure algorithm is needed to limit the sender rate and avoid losses in the proxy. The tail asymptotics analysis surprisingly showed that buffer occupancy and delays in the stationary regime are heavy-tailed. We also performed network simulations (using the *ns-2* software) and developed an event-driven simulator in order to illustrate the analytical results by means of simulations.

In a second part of the work, we gave a representation of the system in terms of "piecewise-deterministic Markov process", by referring the theory of PDPs developed by M.H.A. Davis in the '80s. A PDP is a mixture of deterministic motion and random jumps associated to various configurations of the system. Such formulation turns out to provide a natural representation of the system behaviour via PDEs associated to the stationary regime that we are currently investigating.

6.2. Design and Performance Analysis of Wireless Networks

Keywords: *CDMA/UMTS*, *CSMA*, *Hiperlan*, *IEEE 802.11*, *MAC protocols*, *TCP*, *Wireless LANs*, *ad hoc networks*, *admission and congestion control*, *capacity*, *coverage*, *exponential back-off protocols*, *flow-level performance*, *mean field analysis*, *mesh networks*, *signal to interference ratio*, *stability*, *transport capacity*.

Participants: François Baccelli, Bartek Błaszczyszyn, Yogeshwaran Dhandapani, Bruno Kauffmann.

This axis concerns the analysis and the design of wireless access communication networks, in particular cellular networks, wireless LANs, MANETs, VANETs, sensor networks etc. 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.

6.2.1. Cellular networks

Building upon the scalable admission and congestion control schemes developed in [41], [34], which allow for an exact representation of the geometry of interference in networks, in collaboration with M.K. Karray [Orange Labs] we continue developing a *comprehensive approach to the performance evaluation of cellular networks*. This approach, that resulted in three patents filed by INRIA and FT, has already been recognized by Orange who uses some of our methods in the program *SERT* integrated to its dimensioning tools. This year, the main focus was on the evolution of SERT was on the integration of streaming traffic services.

6.2.1.1. Impact of mean user speed on call blocking and cuts of streaming traffic.

In contrast to data traffic, streaming users require predefined transmission rates, which can be maintained at the price of blocking of some arrivals or cutting some existing connections when a network congestion occurs. The fractions of blocked and cut transmissions in the long run of the system, called respectively, blocking and cut probabilities, are the main performance metrics of such networks. In [21] we evaluated the impact of the intra- and extra-cell user mobility on these metrics. Specifically, we assumed a spatio-temporal Poisson arrival process of streaming calls, independent Markovian mobility and exponential duration of each call. The dynamics of this free (offered) process is modified each time a congestion-generating transition occurs. We considered two possible modifications, which lead to two different loss models. We studied both of them, and in particular, we proposed some explicit approximations for the blocking and cut probabilities, which take into account the mean user mobility speed. We illustrated our approach studying UMTS release 99.

6.2.1.2. Dimensioning of CDMA cellular networks serving streaming traffic

In [20] we propose an efficient analytical method for dimensioning of the downlink radio part of CDMA networks serving real-time calls. The proposed method is based on some admission condition called *average feasibility condition* (AFC). The advantage of using this condition is twofold: It has the well-known multi-Erlang form making the corresponding call blocking probabilities easy to evaluate, using e.g. Kaufman-Roberts algorithm. Moreover, it approximates the necessary and sufficient condition of the feasibility of power allocation (NSFC) that gives an intrinsic and ultimate limitation on the network performance. More precisely, our AFC is some modification of the distributed sufficient condition of the power allocation proposed in [34] and implemented in the *SERT* program of Orange which, in its original form, is too conservative yielding a loss of capacity compared to NSFC of about 25% (for the voice traffic). The modification consists of replacing the other-base-station *maximal power limitation* by an *average emitted power approximation* evaluated in some simple yet pertinent mean network model. We analytically evaluated the call blocking probabilities in the network model with Poisson arrival stream controlled by AFC. Moreover, in order to validate the pertinence of the proposed approach in cellular network dimensioning process, we compared the obtained blocking probabilities to those estimated from simulations of the model running NSFC (in the regimes of interest for the dimensioning process). This comparison shows that AFC yields a gap of capacity of about 5% (for the voice traffic).

6.2.2. 802.11 access networks

6.2.2.1. Self-organizing of 802.11 access networks.

The popularity of IEEE 802.11 WLANs has led to today's dense deployments in urban areas. Such high density leads to sub-optimal performance unless wireless devices interfering in these networks learn how to optimally use and share the spectrum. We proposed a set of distributed algorithms that allow (i) multiple interfering 802.11 Access Points to select their operating frequency in order to minimize interferences, (ii) Access points to tun their transmission power and (iii) users to choose the Access Point they attach to, in order to maximize the sum of the bit-rates obtained by the set of users throughout the network. Typical functions (choosing a channel to operate on, choosing an access point to associate with) were shown to be well-addressed in a common optimization framework based on Gibbs' sampler via the minimization of a potential energy function. This scheme does not require explicit coordination among the wireless devices. For a fixed traffic demand, limited by wireless access, it was shown to achieve a fairness criterion identified in the past as the minimal potential delay [52]. We established the mathematical properties of the proposed algorithms and studied their performance using analytical, event-driven simulations. We discussed implementation requirements and showed that significant benefits can be gained even within incremental deployments and in the presence of non-cooperating wireless clients. A keynote lecture surveying three recent papers on the matter ([50], [55], [54], in collaboration with researchers at INTEL and THOMSON) was presented at the 2008 ACM Sigmetrics conference.

6.2.3. Mobile ad Hoc Networks

A mobile ad-hoc network (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.

6.2.3.1. Opportunistic Aloha.

Spatial Aloha is probably the simplest medium access protocol to be used in a large mobile ad hoc network: Each station tosses a coin independently of everything else and accesses the channel if it gets heads. In a network where stations are randomly and homogeneously located in a plane, there is a way to tune the bias of the coin so as to obtain the best possible compromise between spatial reuse and per transmitter throughput. In the paper [36] that complements [35] we showed how to address this questions using stochastic geometry and more precisely Poisson shot noise field theory. The theory that is developed is fully computational and leads to new closed form expressions for various kinds of spatial averages (like e.g. outage, throughput or transport). It also allows one to derive general scaling laws that hold for general fading assumptions. We exemplified its flexibility by analyzing a natural variant of Spatial Aloha which we call Opportunistic Aloha and which consists in replacing the coin tossing by an evaluation of the quality of the channel of each station to its receiver and a selection of the stations with good channel (e.g. fading) conditions. We showed how to adapt the general machinery to this variant and how to optimize and implement it. We also showed that when properly tuned, Opportunistic Aloha very significantly outperforms Spatial Aloha, with e.g. a mean throughput per unit area twice higher for Rayleigh fading scenarios with typical parameters.

6.2.3.2. Opportunistic routing in MANETs.

We investigated the potential gains of opportunistic routing strategies which take advantage of both time and space diversity compared to classical routing strategies, where packets are routed on a pre-defined route usually obtained by a shortest path routing protocol. In the opportunistic routing scheme we considered, the relay is selected among the nodes having captured the packet transmission (if any) as the node which maximizes some given geographic utility criterion (e.g. minimize the remaining distance to the destination or maximizes the progress of the packet towards the destination). In such a scheme, opportunism consists in taking advantage at each hop of the local pattern of transmission, where locality is understood in both its time and space sense. In our study in [15] we used a spatial version of Aloha for the MAC layer, which has been shown to scale well in multi-hop networks and a well established definition for the capture of packets based on the Signal over Interference and Noise Ratio (SINR) model. Our simulation study shows that such an opportunistic routing scheme outperforms classical routing schemes. It also shows how to optimally tune the MAC parameters so as to minimize the average number of hops from origin to destination everywhere in the network. This optimization is shown by simulation to be independent of the network density, a property that we back by a mathematical proof based on a scale invariance argument.

In the described above opportunistic routing, the current emitter of a given packet does not need to know a priori its next relay, but the nodes which capture this transmission (if any) perform a *self selection* to chose the unique packet relay node and acknowledge the emitter. The primary goal of [14] is to explain how this relay self selection can be achieved in practice. Moreover, we showed that this routing technique works well with various MAC protocols. More precisely, assuming two different MAC protocols (Aloha and CSMA), we compared by simulation the performance of this new routing technique to the conventional shortest path routing. In this particular study we assumed that the self selection chooses the relay minimizing the remaining distance to the destination. This criterion requires that the nodes know their geographic positions. However we showed the even if only a small fraction of nodes in the network knows their positions exactly, e.g. using GPS, and provide this information to the remaining nodes to let them estimate their positions, our technique still works very well and still outperforms conventional routing techniques.

6.2.4. Vehicular Ad-Hoc Networks (VANETs)

Vehicular Ad Hoc NETworks (VANETs) are special cases of MANETs where the network is usually 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. Two kinds of traffic can be distinguished in a VANET:

- *broadcast* or *multicast* oriented; this kind of traffic will be primarily generated by safety applications: for instance when an emergency message is broadcasted after a car crash to warn other vehicles in the vicinity of the car crash. It can also be generated by usual information broadcast;
- *point-to-point traffic* generated by added-value services such as entertainment, Internet access, etc.

Besides the importance of emergency broadcast applications, VANETs differ from the general MANETs, which are usually modeled on the plane (i.e. in 2D), in that they are typically considered on a line (i.e., in 1D). In our study of VANETs, effectuated in collaboration with Paul Mühlethaler [INRIA HIPERCOM], we built upon the methodology developed for MANETs adapting it to the specificity of these particular mobile ad-hoc networks.

6.2.4.1. Opportunistic broadcasting of safety messages.

A key challenge in such a scenario is to design an efficient broadcast strategy that quickly disseminates the packets in the VANET. While several protocols have been proposed, most of them are based on the proactive and reactive routing protocols of general MANETs and do not fulfill the tight time constraints and high delivery ratio required by VANET safety applications. In [23] we presented an opportunistic routing protocol that uses a modified 802.11 MAC layer to select the best relay from all the vehicles that have correctly received the packet. This MAC layer technique allows for a quick and efficient selection and does not need mechanisms to prevent duplicate transmissions. The analysis of the ns-2 simulation results show that it is highly suited for VANET safety applications.

6.2.4.2. Comparison of conventional routing vs an advanced opportunistic routing scheme using active signaling.

In [22] we studied the benefits of opportunistic routing in the context of point to point traffic. In contrast to previous studies, we used an optimized selection of potential relays to build our opportunistic routing protocol. This technique allows a logarithmic selection of the relays whereas already existing systems use a linear selection. Using extensive simulations, we compared this new routing technology with conventional shortest path routing techniques. We used two access techniques: the first one is a simple slotted Aloha scheme, and the other a CSMA scheme.

6.2.4.3. Optimizing throughput in linear VANETs.

In [42] we adapted the stochastic geometry framework previously worked out for planar MANETs to propose two models of point to point traffic for Aloha-based linear VANETs. The first one uses a SINR capture condition to qualify a successful transmission, while the second one express the transmission throughput as a function of SINR using Shannon's law. Assuming a Poisson repartition of vehicles, a power-law mean path-loss and a Raleigh fading, we derived explicit formulas for the probability of a successful transmission on a given distance and the mean throughput, respectively. Furthermore, we optimize two quantities directly linked to the achievable network throughput: the mean density of packet progress and the mean density of information transport. This is realized by tuning the communication range and the probability of channel access. We also present numerical examples and study the impact of the external noise on the optimal tuning of network parameters.

6.2.5. Sensor Networks

6.2.5.1. Non-slotted Aloha Mac model with applications to transmit-only sensor networks.

In [43], we proposed and analyzed a probabilistic model of packet reception in the steady state regime of a non-slotted wireless communication channel as used in certain classes of transmit-only radios. This can be viewed as an extension of the classical M/D/1/1 Erlang loss model where the *interference* created by different packet emissions is introduced by means of the shot-noise process. More precisely, we assume that a given packet is admitted by the receiver if this latter is idle at the packet arrival epoch and successfully received if, in addition, its signal-to-interference-and-noise ratio averaged over the reception period is large enough. As the main results we proved an analog of the Erlang formula for the fraction of the packets that are successfully received.

In [24] we considered a hybrid wireless sensor network with regular and transmit-only sensors. The transmit-only sensors do not have the receiver circuit, hence are cheaper and less energy consuming, but their transmissions cannot be coordinated. Regular sensors, also called cluster-heads, are responsible for receiving information from the transmit-only sensors and forwarding it to sinks. Using a mathematical model of random access networks developed in [43] we defined and evaluated packet admission policies at cluster heads for different performance criteria. We showed that the proposed hybrid network architecture, using the optimal policies, can achieve substantial dollar cost and power consumption savings as compared to conventional architectures while providing the same performance guarantees.

6.2.5.2. Tracking and Coverage in Sensor Networks.

The aim of the model reported in [10] is to analyze the tracking of a target and the coverage in sensor networks. These have potential applications in intruder detection, surveillance of an area and various other military and medical applications. We model an unreliable sensor network by a Markov-Poisson-Boolean model. The model is the usual Poisson-Boolean model but with the possibility that the nodes can be in two states — on or off. The on-off process of the nodes evolve as i.i.d. two-state Markov chains. We characterized the ability of such a network to track linearly moving targets. We sketched the limit laws (strong law and central limit theorem) for fraction of the time the moving target is tracked. Apart from scaling of the intensity of the Poisson point process, we also considered scaling of the on-off rates of the Markov chains. Also, we demonstrated how to extend the results when a further condition that k-sensors track the target at a given point of time is imposed.

6.3. Network Dynamics

Keywords: *Lyapounov exponent*, *Queueing network*, *Veraverbeke's theorem*, *estimator*, *insensitivity*, *inversion formula*, *large deviation*, *max-plus algebra*, *monotone-separable networks*, *probing*, *product-form networks*, *rare event*, *sub-additivity*, *sub-exponential distribution*.

Participants: François Baccelli, Bruno Kauffmann, Marc Lelarge, Frédéric Morlot.

6.3.1. Rare Events in Stochastic Networks

6.3.1.1. Asymptotics of subexponential max-plus network and packet reordering.

In a paper [45] with Ton Dieker we extended previous results obtained with Serguei Foss in [37]. We studied the stationary solution to a (max, plus)-linear recursion. Our results are valid for quite general networks. In [11], we illustrated this by studying the asymptotics of the resequencing delay and the size of the resequencing buffer due to multi-path routing. Due to random delays over different paths in a system, the packets or updates may arrive at the receiver in a different order than their chronological order. In such a case, a resequencing buffer at the receiver has to store disordered packets temporarily. In [11], we analyzed both the waiting time of a packet in the resequencing buffer and the size of this resequencing queue. We derived the exact asymptotics for the large deviation of these quantities under heavy-tailed assumptions. In contrast with results obtained for light-tailed distributions, we showed that there exists several "typical paths" that lead to the large deviation. We derived explicitly these different "typical paths" and gave heuristic rules for an optimal balancing.

6.3.1.2. Tail asymptotics for Discrete Event Systems

In the context of communication networks, the framework of stochastic event graphs allows a modeling of control mechanisms induced by the communication protocol and an analysis of its performances. In [12], we concentrated on the logarithmic tail asymptotics of the stationary response time for a class of networks that admit a representation as (max,plus)-linear systems in a random medium. We were able to derive analytical results when the distribution of the holding times are light-tailed. We showed that the lack of independence may lead in dimension bigger than one to non-trivial effects in the asymptotics of the sojourn time. We also studied in detail a simple queueing network with multipath routing.

6.3.2. Queueing Theory for Active Probing

6.3.2.1. Inversion 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. These inverse problems in queueing theory are a new research field, and has drawn little attention from a theory point of view. We are currently interested in building the foundations of the domain : how can we define inverse problems in queueing theory? Which one admits one unique solution? What are the limitations of this approach? How to classify the networks and the estimators one can study?

6.3.2.2. Internet Tomography.

Active probing suffers presently of the "Bottleneck" limitation: all characteristics of the path after the bottleneck link are unreachable with current techniques. The bottleneck link erases all the later effects. One of the reason of this limitation is that all known techniques uses "ad-hoc" situation to remove the randomness of the network. In a joint work with Darryl Veitch [University of Melbourne, Australia; TREC's associate team], we are currently investigating a new tomography technique, based on the measurements of point-to-point end-to-end delays, exploiting the fluctuations of these delays and the temporal series to have insight information about the networks characteristics. In [38], we combine classical queueing theory models with statistical analysis to obtain estimators of residual bandwidth on all links of the path. These estimators are proved to be tractable, consistent and efficient. We evaluate their performance with simulation and trace-based experiments.

6.3.3. Exploration of an influence-based user mobility model

The goal of this work in progress is to model wireless communication geographic hot spots and the related user mobility. More precisely, in a urban area that contains some "attractive" zones (e.g. malls, railway stations, parks, big squares, etc.) one observes a phenomenon of traffic hot spots (accumulations of users), which appear and disappear in time in different attractive zones. In the case of data networks deployed in this area, the proper modeling of these hot-spots is necessary to enhance location-based services and protocols (such as e.g. access points caching of frequently accessed data). To cope with the phenomenon of traffic hot spots appearing in the attractive zones, we studied some Markov model that we call the "sheep model", where the mutual correlation of individual user mobility is particularly strong. First, in the two-state case (two attractive geographic locations) we found closed form expressions for hot-spot transition durations and transition probabilities. We also gave asymptotic approximations of these expressions, and upper bounds of the convergence speed. Next, we generalized these results to the many-state case. We also introduced "rebelliousness" and "siphoning" in our model, in order to avoid absorbing states and to make the previous model more realistic. We defined macro-states and computed transition durations between them. Finally, using the "siphoning", we explained how to use real measurements to calibrate our mobility model.

6.4. Economics of Networks

Keywords: *Epidemic risk model*, *Insurance*, *Security*, *diffusion of innovations*.

Participants: Hamed Amini, Marc Lelarge.

6.4.1. Analysis of Security Investments in Networks

Getting new security features and protocols to be widely adopted and deployed in the Internet has been a continuing challenge. There are several reasons for this, in particular economic reasons arising from the presence of network externalities. Indeed, like the Internet itself, the technologies to secure it exhibit network effects: their value to individual users changes as other users decide to adopt them or not. In particular, the benefits felt by early adopters of security solutions might fall significantly below the cost of adoption, making it difficult for those solutions to gain attraction and get deployed at a large scale.

With Jean Bolot (SPRINT), our goal in [26] and [25] is to model and quantify the impact of such externalities on the adoptability and deployment of security features and protocols in the Internet. We studied a network of interconnected agents, which are subject to epidemic risks such as those caused by propagating viruses and worms, and which can decide whether or not to invest some amount to deploy security solutions. Agents experience negative externalities from other agents, as the risks faced by an agent depend not only on the choices of that agent (whether or not to invest in self-protection), but also on those of the other agents. Expectations about choices made by other agents then influence investments in self-protection, resulting in a possibly suboptimal outcome overall.

We presented and solved an analytical model where the agents are connected according to a variety of network topologies. Borrowing ideas and techniques used in statistical physics, we derived analytical solutions for sparse random graphs, for which we obtained asymptotic results. We showed that we can explicitly identify the impact of network externalities on the adoptability and deployment of security features. In other words, we identified both the economic and network properties that determine the adoption of security technologies. Therefore, we expect our results to provide useful guidance for the design of new economic mechanisms and for the development of network protocols likely to be deployed at a large scale.

6.4.2. Cyber Insurance as an Incentive for Internet Security

Managing security risks in the Internet has so far mostly involved methods to reduce the risks and the severity of the damages. Those methods (such as firewalls, intrusion detection and prevention, etc) reduce but do not eliminate risk, and the question remains on how to handle the residual risk. In this paper, we consider the problem of whether buying insurance to protect the Internet and its users from security risks makes sense, and if so, of identifying specific benefits of insurance and designing appropriate insurance policies.

Using insurance in the Internet raises several questions because entities in the Internet face correlated risks, which means that insurance claims will likely be correlated, making those entities less attractive to insurance companies. Furthermore, risks are interdependent, meaning that the decision by an entity to invest in security and self-protect affects the risk faced by others. We analyze the impact of these externalities on the security investments of the users using simple models that combine recent ideas from risk theory and network modeling.

Our key result with Jean Bolot (SPRINT) in [18], [19] is that using insurance would increase the security in the Internet. Specifically, we showed that the adoption of security investments follows a threshold or tipping point dynamics, and that insurance is a powerful incentive mechanism which pushes entities over the threshold into a desirable state where they invest in self-protection. Given its many benefits, we argued that insurance should become an important component of risk management in the Internet, and discussed its impact on Internet mechanisms and architecture.

6.4.3. Diffusion of Innovations on Random Networks

Viral marketing takes advantage of preexisting social networks among customers to achieve large changes in behaviour. Models of influence spread have been studied in a number of domains, including the effect of “word of mouth” in the promotion of new products or the diffusion of technologies. A social network can be represented by a graph where the nodes are individuals and the edges indicate a form of social relationship. The flow of influence through this network can be thought of as an increasing process of active nodes: as individuals become aware of new technologies, they have the potential to pass them on to their neighbours. The goal of marketing is to trigger a large cascade of adoptions. In [29], with Moez Draief (Imperial College) we developed a mathematical model that allows to analyze the dynamics of the cascading sequence of nodes switching to the new technology. To this end we described a continuous-time and a discrete-time models and analyse the proportion of nodes that adopt the new technology over time.

In [27], we analyzed diffusion models on sparse random networks with neighborhood effects. We showed how large cascades can be triggered by small initial shocks and compute critical parameters: contagion threshold for a random network, phase transition in the size of the cascade.

6.5. Point Processes, Stochastic Geometry and Random Graphs

Keywords: *Boolean model*, *percolation*, *point process*, *random tessellation*, *shot-noise*, *stochastic comparison*, *stochastic geometry*.

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

6.5.1. Book on Stochastic Geometry

TREC is actively working on a book project focused on the use of the stochastic geometry framework for the modeling of wireless communications.

Stochastic geometry is a rich branch of applied probability which allows to study random phenomenons on the plane or in higher dimension. It is intrinsically related to the theory of point processes. Initially its development was stimulated by applications to biology, astronomy and material sciences. Nowadays, it is also used in image analysis. During the 03-08 period, we contributed to proving that it could also be of use in the context of wireless communication networks. The reason for this is that the geometry of the location of mobiles and/or base stations plays a key role since it determines the signal to interference ratio for each potential channel and hence the possibility of establishing simultaneously some set of communications at a given bit rate.

Stochastic geometry provides a natural way of defining (and computing) macroscopic properties of wireless networks, by some averaging over all potential geometrical patterns for e.g. the mobiles. Its role is hence similar to that played by the theory of point processes on the real line in the classical queueing theory. The methodology was initiated in [33], [35] and it was further developed through several papers including [43], [50], [55], [56], [36], [24].

The book [40] that is currently under review will survey these papers and more recent results obtained by this approach for analyzing key properties of wireless networks such as coverage or connectivity, and for evaluating the performance of a variety of protocols used in this context such as medium access control or routing.

6.5.2. Research on Stochastic Ordering of Random Measures and Shot-Noise Fields

Stochastic geometric models of wireless networks have in general been investigated under Poissonian setting (see [33], [35]). The first aim of the PhD thesis of Yogeshwaran D. is to study certain performance measures of wireless networks using stochastic geometric tools in the non-Poissonian setting. Due to the difficulty in obtaining closed-form expressions for various performance measures in non-Poissonian settings (see [60]), we attempted a qualitative study of the performance measures. Relying extensively on the theory of stochastic ordering, we study the effects of ordering of random measures on ordering of shot-noise fields generated by the respective random measures. It is to be noted that shot-noise fields form a rich class of performance measures associated with spatial wireless networks. As applications of our results, we obtain comparison of various quantities associated with spatial wireless networks especially SINR (signal-to-interference-noise ratio) models. Also, these results can be of independent interest in the theory of stochastic ordering and stochastic geometry. This work is the subject of a paper [30]. With the help of these results and numerical analysis, we are re-visiting [60] to quantify more accurately the difference between performances of SINR networks with Poisson-Poisson cluster node density and Poisson node density.

6.5.3. Information Theory and Stochastic Geometry

In a joint work with Venkat Anantharam (UC Berkeley) [13], a new class of problems was defined in the theory of Euclidean point processes, motivated by the study of the error exponent (reliability function) for additive noise channels in Information Theory. Each point of the point process is seen as a codeword and the additive noise as a random displacement from this point. Decoding is successful when the displacement of a point falls in the Voronoi cell of this point. For a wide class of point processes that have incarnations in all dimensions, there is a 0–1 law on the probability of successful decoding when dimension goes to infinity. This can be seen as an extension of Shannon's capacity theorem and error exponents can also be defined within this context. For the case of Gaussian noise this approach gives an interesting perspective on the Poltyrev exponent. It also suggests an approach to attack the long standing gap between the best known lower and upper bounds on the reliability function of the traditional AWGN channel, using techniques from point process theory. In particular, it looks quite promising to investigate the error exponents associated with Gibbsian or determinental point processes.

6.5.4. 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); [47]. 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. An edge exists between any two pair of nodes if the distance between them is less than some critical threshold. A variant of the above model that exhibits the union of the coverage regions of all nodes is also referred to in stochastic gemerty as the Boolean model. This naturally means that the communicating entities within a certain physical distance are assumed to be able to communicate with each other. Asymptotic properties of such models as the number of vertices become large have been extensively studied. For example, it has been shown in [58] that for uniformly distributed nodes according to a Poisson point process with intensity n, the critical radius for connectivity scales as $\sqrt{\log\ n/n}$. Results such as this have been used by various authors (for example, [48], [46]) to derive the capacity of such networks. Various other properties of wireless networks such as routing algorithms have also been designed using various asymptotic properties. A comprehensive review of the existing results can be found in the monographs [53], [57] and a recent publication [46] more oriented towards applications in communication networks. In collaboration with Srikanth Iyer [Indian Institute of Science, Bangalore, India] we work on a few particular problems related to RGG.

6.5.4.1. AB Random Geometric Graphs

We are interested in a RGG model where nodes are of two types and only nodes of opposite type close to each other connect. Such a model has been already considered on discrete lattices. We showed the existence of phase transition for percolation in such a model as well as characterized the critical intensity in terms of the critical intensity of a related Poisson Boolean model. We answered a few other percolation-theoretic questions like uniqueness of the giant component, bounds for the critical intensity etc. In the second part, we ascertained the asymptotic regime of the radius for connectivity under natural assumptions on the intensity of the Poisson point process. This is a work in progress ([49]).

6.5.4.2. Connectivity in Random Geometric Graphs with Fading

In [44], we investigated the impact of the fading effect on the RGG that arise in wireless communication. Such graphs have oriented edges. Moreover, the fading may essentially modify the topology of the network otherwise fully described by the Eulidean location of nodes and the path loss function. Connectivity as well as local properties of these graphs play an important role in opportunistic MAC/routing schemes.

6.5.5. Routing on Time-Space SINR Graphs

The following mathematical formalism proposed in [15] is useful when studying macroscopic properties of routing in MANETs. One can model the users of a mobile as points of a stochastic point process where each node can be a transmitter or receiver in each time step. The SINR graph is a geometric graph where the nodes are the points of a point process and an edge is present between a transmitter and a receiver if the SINR at the receiver is above a certain threshold. Due to fluctuations in propagation and MAC, these edges vary in time. By a route we mean a path between two distant nodes made of a sequence of contiguous edges (by contiguous, we mean in time and space: at each time step, one should use some feasible edge of the graph that originates from the end point of the edge used in the previous step).

In the above time-space SINR graph we studied both optimal and 'greedy' (opportunistic in the sense described in Section 6.2.3) routes. In both cases, these are random geometric objects built on the underlying point process. We proved that under so called Rayleigh fading, optimal paths do not have a sub-linear growth. This is an opening to the PhD thesis of Mir-Omid Haji-Mirsadeghi, whose main objective is the asymptotic analysis of long routes within this setting.

6.6. Combinatorial Optimization and Analysis of Algorithms

Keywords: *combinatorial optimization*, *local weak convergence*, *scaling exponent*.

Participants: Marc Lelarge, Justin Salez.

6.6.1. Belief propagation for the Random Assignment Problem

Belief propagation is a non-rigorous decentralized and iterative algorithmic strategy for solving complex optimization problems on huge graphs by purely-local propagation of dynamic messages along their edges. Its remarkable performance in various domains of application from statistical physics to image processing or error-correcting codes have motivated a lot of theoretical works on the crucial question of convergence of beliefs despite the cycles, and in particular the way it evolves as the size of the underlying graph grows to infinity. However, a complete and rigorous understanding of those remarkable emergence phenomena (general conditions for convergence, asymptotic speed and influence of the initialization) still misses. A new idea consists in using the topological notion of local weak convergence of random geometric graphs to define a limiting local structure as the number of vertexes grows to infinity and then replace the asymptotic study of the phenomenon by its direct analysis on the infinite graph.

This method has already allowed us to establish asymptotic convergence at constant speed for the special case of the famous optimal assignment problem, resulting in a distributed algorithm with asymptotic complexity $O(n^2)$ compared to $O(n^3)$ for the best-known exact algorithm. This is joint work with Devavrat Shah (MIT). It has been accepted for publication in the Journal of Mathematics of Operations Research [59] and Justin Salez will also present the results at the SODA'09 conference, http://www.siam.org/meetings/da09/, New-York, in January 2009. We hope this method will be easily extended to other optimization problems on tree-like graphs and will become a powerful tool in the fascinating quest for a general mathematical understanding of Belief Propagation.

6.6.2. Combinatorial optimization and its scaling exponents

Freshman calculus tells us how to find a minimum x_* of a smooth function $f(x)$: set the derivative $f'(x_*) = 0$ and check $f''(x_*) > 0$. The related series expansion tells us, for points x near to x_*, how the distance $\delta = |x - x_*|$ relates to the difference $\epsilon = f(x) - f(x_*)$ in f-values: ϵ scales as δ^2. This *scaling exponent* 2 persists for functions $f : \mathbb{R}^d \to \mathbb{R}$: if x_* is a local minimum and $\epsilon(\delta) := \min\{f(x) - f(x_*) : |x - x_*| = \delta\}$, then $\epsilon(\delta)$ scales as δ^2 for a generic smooth function f.

Combinatorial optimization, exemplified by the *traveling salesman problem* (TSP), is traditionally viewed as a quite distinct subject, with theoretical analysis focusing on the number of steps that algorithms require to find the optimal solution. To make a connection with calculus, compare an arbitrary tour $\mathbf{x}$ through n points with the optimal (minimum-length) tour $\mathbf{x}_*$, by considering the two quantities

$$\delta_n(\mathbf{x}) = \{\text{number of edges in } \mathbf{x} \text{ but not in } \mathbf{x}_*\}/n$$
$$\epsilon_n(\mathbf{x}) = \{\text{length difference between } \mathbf{x} \text{ and } \mathbf{x}_*\}/s(n)$$

where $s(n)$ is the length of the minimum length tour. Now define $\epsilon_n(\delta)$ to be the minimum value of $\epsilon_n(\mathbf{x})$ over all tours $\mathbf{x}$ for which $\delta_n(\mathbf{x}) \geq \delta$. Although the function $\epsilon_n(\delta)$ will depend on n and the problem instance, we anticipate that for typical instances drawn from a suitable probability model it will converge in the $n \to \infty$ limit to some deterministic function $\epsilon(\delta)$. The *universality* paradigm from statistical physics suggests there might be a scaling exponent α defined by

$$\epsilon(\delta) \sim \delta^\alpha \text{ as } \delta \to 0$$

and that the exponent should be robust under model details.

There is fairly strong evidence that for TSP the scaling exponent is 3. This is based on analytic methods in a *mean-field* model of interpoint distances (distances between pairs of points are random, independent for different pairs, thus ignoring geometric constraints) and on Monte-Carlo simulations for random points in 2, 3 and 4 dimensional space. The analytic results build upon a recent probabilistic reinterpretation of the work of Krauth and Mézard establishing the average length of mean-field TSP tours. But neither part of these TSP assertions is rigorous, and indeed rigorous proofs in d dimensions seem far out of reach of current methodology.

6.6.2.1. Minimal Spanning Trees

In [8], with David Aldous (UC Berkeley) and Charles Bordenave (CNRS), we studied the relation between the minimal spanning tree (MST) on many random points and the "near-minimal" tree which is optimal subject to the constraint that a proportion δ of its edges must be different from those of the MST. Heuristics suggest that, regardless of details of the probability model, the ratio of lengths should scale as $1 + \Theta(\delta^2)$. We proved this scaling result in the model of the lattice with random edge-lengths and in the Euclidean model.

6.6.2.2. Dynamic Programming Optimization over Random Data

A very simple example of an algorithmic problem solvable by dynamic programming is to maximize, over $A \subseteq \{1, 2, ..., n\}$, the objective function $|A| - \sum_i \xi_i \mathbb{1}(i \in A, i + 1 \in A)$ for given $\xi_i > 0$. This problem, with random (ξ_i), provides a test example for studying the relationship between optimal and near-optimal solutions of combinatorial optimization problems. In [31] we showed that, amongst solutions differing from the optimal solution in a small proportion δ of places, we can find near-optimal solutions whose objective function value differs from the optimum by a factor of order δ^2 but not smaller order. We conjecture this relationship holds widely in the context of dynamic programming over random data, and Monte Carlo simulations for the Kauffman-Levin NK model are consistent with the conjecture. This work is a technical contribution to a broad program initiated in Aldous-Percus (2003) of relating such scaling exponents to the algorithmic difficulty of optimization problems.

7. Contracts and Grants with Industry

7.1. Research Grant of Thomson

Participants: François Baccelli, Bartek Błaszczyszyn, Bruno Kauffmann.

The collaboration with the new Paris Lab of THOMSON has been developing very fast since its creation. The scientific ties with C. Diot, L. Massoulié and A. Chaintreau are quite strong and materialize into:

- joint seminars and reading groups, notably the new Paris-Networking series (http://www.paris-networking.org/) that we jointly initiated.
- joint research actions, particularly on routing in ESS mesh WiFi networks and on CDMA networks; these actions were presented at the *INRIA / THOMSON Workshop* organized at ENS Paris, December 17 (http://www.paris-networking.org/display_event.php?dispID=482),
- a grant from Thomson which allows us to invite well known scientists in Communications (like e.g. V. Anantharam from Berkeley);
- various ongoing projects of joint proposals in national and European agencies; in particular we will soon start an ANR project on network measurements called C'mon.
- a joint patent on routing in mesh networks.

7.2. Sprint ATL Grant

Participants: François Baccelli, Marc Lelarge.

The interaction with the research lab of Sprint (Sprint ATL, in Burlingame, California) is made possible through a research grant. This interaction has been focused on two main topics:

- The design of active probing methods for the estimation of internal properties of core or access networks based on end-to-end measurements. In the paper [51] we proposed inversion formulas allowing one the analyze the law of cross traffic in a router from the end-to-end delay of probes. We also investigated the limitations of such inversion formulas. There are several continuations of this line of thoughts currently under investigation.
- The analysis of risks on the Internet. In [26] and [25], we present a general framework to study strategic behavior of agents facing epidemic risks on a network such as viruses or worms. In [18] and [19], we consider the problem of whether buying insurance to protect the Internet and its users from security risks makes sense, and if so, of identifying specific benefits of insurance and designing appropriate insurance policies.

Other projects have been started on the architecture of heterogeneous wireless networks. This collaboration is quite fruitful. It lead to several joint papers this year.

7.3. EADS PhD fund

Participants: François Baccelli, Bartek Błaszczyszyn, Yogeshwaran Dhandapani.

This 6 year grant started in September 06 and bears on the modeling of mobile ad hoc networks. It allowed us to hire in 2007 a PhD student, D. Yogeshwaran from IISc Bangalore. The work of D. Yogeshwaran bears on the stochastic comparison of random measures, point process and shot-noise fields. A reading group on permanental and determinental point processes, that respectively exhibit attraction and repulsion, was conducted by Yogeshwaran Dhandapani and Frédéric Morlot.

7.4. Research Contract with Alcatel Bell "Choking of UDP traffic"

Participant: François Baccelli.

In 2008 we completed the second phase of a research project with the Network Strategy Group of Alcatel Antwerp (Danny de Vleeschauwer and Koen Laevens) and with N2NSoft (Dohy Hong). This project was focused on the modeling of the interaction of a large collection of CBR multimedia sources that join and leave and that share an access network. The main objective was the design of optimal choking policies for the transport of layer encoded video in such an access networks. The methodology that we used and implemented is based on the theory of Markov Decision. The third phase of the project was approved lately and bears on the VBR case.

7.5. Collaboration with Researchers of France Télécom

Participants: François Baccelli, Bartek Błaszczyszyn, Frédéric Morlot.

As in 2007, in 2008 the collaboration with France Télécom is not part of any formal framework and is under the form of "Spontaneous Collaborations" with two researchers:

- Mohamed Karray, with whom we work on the coverage and capacity of the CDMA, UMTS and OFDM networks. This resulted in three patents filed by INRIA and FT. The pertinence of our approach has already been recognized by Orange. This operator uses some of our methods in the program *SERT* integrated to its dimensioning tools. This year the collaboration lead to two publications on the performance evaluation and dimensioning of these networks serving streaming traffic (see Section 6.2.1).
- Frdédéric Morlot, who started a PhD under supervision of F. Baccelli in 2007. The work of Frédéric Morlot bears on the modeling of hot spots and on the motions compatible with such hot spots. F. Morlot introduced the "sheep model" (see Section 6.3.3) and obtained several analytical results on it. Then, in order to calibrate his model, for six moths he has been retrieving localization data in Orange's mobile networks (Paris, Bucarest, Warsaw, Krakaw, Madrid, Barcelona).

8. Other Grants and Activities

8.1. Networks and International Working Groups

- The France-Stanford Center has accepted a joint project entitled "Analysis and Design of Next-Generation Wireless Networks" This project was funded in 2006-2007. The collaboration with Stanford went on in 2008: a second joint paper on power control was submitted [32]. A joint patent was also filed by Stanford University and INRIA.
- TREC obtained in November 2006 the INRIA status of *Associated Lab* (équipe associée) for the group of Prof. Darryl Veitch of the University of Melbourne (http://www.cubinlab.ee.unimelb.edu.au/~darryl/index.html) for developing our joint research action on active probing. This was continued for a second year from Nov. 2007 to Nov. 2008. We have a series of joint papers on these questions. This year, and F. Baccelli visited the University of Melbourne for 2 weeks. Also D. Veitch visited TREC for 3 weeks. Two joint papers were submitted this year and one more is under preparation.
- TREC is currently a partner of the *European Network of Excellence (NoE)* called Euro-FGI (http://eurongi.enst.fr/en_accueil.html). This NoE, which is focused on the next generation Internet and is the continuation of the NoE Euro-NGI (2004–2006), is led by Groupement des Ecoles de Télécoms (GET) and has about 50 partners. TREC is also a partner in the new NoE (starting 2007) Euro-NF which gathers a smaller group of about 30 partners (http://eurongi.enst.fr/p_en_menu1_NFcommunit_396.html) with a main focus on the Future Internet.
- TREC is a partner in ARC IFANY (http://www-sop.inria.fr/mistral/personnel/Eitan.Altman/ifany/), which is focused on Information Theory and which also includes the Maestro, Armor, Hipercom project teams of INRIA and other partners like EURECOM, EPFL and INT. The work of TREC on the matter is centered on the evaluation of the capacity of large wireless networks.

9. Dissemination

9.1. Animation of the Scientific Community

9.1.1. TREC's seminar

the following scientists gave talks in 2008:

- France
  - Fabien Mathieu from the *France Télécom R&D*, talking on "Epidemic Live Streaming: Optimal Performance Trade-offs"; February 15;
  - Florian Simatos from the *Groupe INRIA RAP*, talking on "A stochastic Model of a File Sharing Principle"; February 15,
  - Yogeshwaran Dhandapani from the *ENS, Paris*, talking on "Directionally Convex Ordering of Random Measures, shot-Noise fields and some applications to wireless networks"; February 26,
  - André Goldman from the *UFR de Mathématiques, Université Claude Bernard Lyon 1*, talking on "Questions de couplage et de conditionnement pour les processus determinantaux."; March 27,
  - Charles Bordenave from the *CNRS-Université Toulouse*, talking on "Load optimization in spatial networks"; Otober 29,
  - Yousra Chabchoub from *INRIA*, Paris, talking on, "Detecting DoS attacks via Bloom filters"; November 19,
- Europe
  - Anastasios Giovanidis from the *Heinrich Hertz Institute of Berlin, Germany*, talking on "Performance optimization of Automatic Retransmission reQuest (ARQ) protocols in wireless communication systems"; July 3,
  - Thomas Liniger from the *ETH Zürich, Switzerland*, talking on "Multivariate Hawkes Processes and Applications in Finance"; July 7,
  - Douglas Leith from the *National University of Ireland*, talking on "WLAN channel selection without communication"; September 24,
  - Alexandre Rybko from the *Russian Academy of Sciences*, talking on "Poisson Hypothesis for Low Load"; Otober 30,
  - Nikita Vvedenskaya from the *IITP, Moscow*, talking on "Configuration of overloaded servers in a network with dynamic routing"; November 12,
  - Thomas Voice from *University of Cambridge, UK* talking on "Stochastically Scalable Flow Control"; November 21,
  - Ben Parker from *School of Mathematical Sciences, London* talking on "Design of Experiments for Markov Chains"; November 24.
- Asia, Australia, Canada, USA
  - Stratis Ioannidis from the *University of Toronto*, talking on " The Design of Hybrid peer-to-peer Systems", February 15,
  - Daryl Daley from the *University of Canberra, Australia*, talking on "A system of finite line-segments from the the Lilypond Protocol"; February 22,
  - Ravi R. Mazumdar from the *University of Waterloo, Canada*, talking on "How many simultaneous users can be supported under fading conditions?"; March 10,

- Venkat Anantharam from the *University of California, Berkeley*, talking on “Efficiency of Selfish Investiments in Network Security.”; June 30,
- Jens Grossklags from the *UC Berkeley, School of Information*, talking on “Secure or Insure? Security investment (failures) in five economic environments; July 24,
- Vivek Borkar from the *School of Technology and Computer Science, Mumbay, India*, talking on “Introduction to reinforcement learning”; September 11,
- Paul Tune from the *University of Melbourne*, talking on “Towards Optimal Sampling for Flow Size Estimation”; November 7,
- Darryl Veitch from the *CUBIN (ARC Centre for UltraBroadband Information Networks)*, Melbourne, talking on “Improving Wireless Security Through Network Diversity”; November 19.

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).
- M. Lelarge animates the project-team seminar http://www.di.ens.fr/~trec/.
- Yogeshwaran animates the internal working seminar.
- B. Błaszczyszyn is a member of the organizing committee of the Scientific Colloquium of INRIA Rocquencourt *Le modéle et l'algorithme* (http://www-c.inria.fr/Internet/actualites/retour-sur-le-dernier-expose-de-la-serie-le-modele-et-l-algorithme).
- 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

MPRI Graduate Course (M2) on “Dynamics and Algorithmics of Communication Network” by F. Baccelli, J. Mairesse (40h); program *Mastère Parisisien de Recherche en Informatique*

University of Pierre and Marie Curie, Paris 6

- Graduate Course on point processes, stochastic geometry and random graphs (program ”Master de Sciences et Technologies”), by F. Baccelli, B. Blaszczyszyn and L. Massoulié (45h).

Ecole Normale Supérieure

- Undergraduate course (master level) of F. Baccelli, P. Brémaud on applied probability (48h).

9.3. Invitations and Participation in Conferences

H. Amini

- Presentations at the International Conference on Economic Science with Heterogeneous Interacting Agents ESHIA / WEHIA (Warsaw, Poland, June 2008; http://science24.com/event/eshia2008/).
- Participation in the following conferences:

    * Stochastic Networks Conference (ENS Paris, June 2008; http://www.liafa.jussieu.fr/~gmerlet/StochasticNetworks/);
    * Workshop on Interacting Particle Systems Statistical Mechanics and Probability Theory (Paris, December 2008; http://interacting.math.cnrs.fr/);

François Baccelli

  - Co supervision of the thesis of H. Q. Nguyen [7] (ENST).
  - Member of the thesis committee of M. Debbah (Habilitation, Paris Sud).
  - Member of the hiring committee of the Hamilton Institute (Dublin).
  - Reviewer of the thesis of J. Galtier (Orange Labs).
  - Co-chair of the 4th workshop on Spatial Stochastic Modeling of Wireless Networks (SpaSWiN 2008) http://www.spaswin.org/2008/, in conjunction with WiOpt 2008 http://www.wiopt.org/wiopt08/.
  - Co-chair of the Stochastic Network Conference 2008, Paris (ENS).
  - Chair of the *Séance publique sur les sciences de l'information* held by the French Academy of Sciences, Paris January 2008.
  - Member of the program committee of IEEE Infocom'08, HotMetrics'08.
  - "Cours de rentrée de la majeure de mathématiques de l'école polytechnique", Hyères, September 08.

- Keynote lectures:
  - International Symposium on Wireless Pervasive Computing (IEEE ISWPC'08), Santorini, Greece, May 2008 (Wireless Network Modeling);
  - International Conference on Measurement and Modeling of Computer Systems (ACM Sigmetrics), Annapolis, Maryland, USA, June 2008 (Measurement Based Self-Optimization of Wireless Networks using Gibbs Fields);
  - Journées de Modélisation Aléatoire et de Statistiques (Journées MAS 08), August 2008, Rennes (Stochastic Geometry);
  - I2010 Conference, Paris, September 2008 (The Future of the Internet);
  - Symposium on Autonomous and Spontaneous Networks, November 2008 (Network Self Organization);
  - ICT 2008 Conference, November 2008, Lyon (The Future of the Internet).
- Presentation at the following conferences:
  - Model35, Rocquencourt, January 08;
  - 7-th World Congress of Probability and Statistics, Singapore, July 08 (invited);
  - Oberwolfach Conference on Stochastic Geometry, Oberwolfach, Germany, October 08 (invited);
  - Workshop for the retirement of G.J. Olsder, Delft, The Netherlands, November 08 (invited).
- Presentation at the following seminars:
  - Iliatech, Rocquencourt (Séminaire WiFi), January 08;
  - Bell Laboratories, Murray Hill (Maths Center), June 08;
  - National University of Singapore, Department of Mathematics, July 08;
  - Docomo Labs, Palo Alto, USA, April 08.

- Scientific adviser of the “Direction Scientifique” of INRIA for communications.
  - Edition of the ICCE (Information, Communication and Computation Everywhere) document for the new strategic plan;
  - Chairman of the think tank “Internet du Futur” commissioned by DGE.
  - Member of the CSTL committee (on the evolution of the French Research Intitutes), October-December 08.

Bartek Błaszczyszyn

- Defended in 2008 his “Habilitation” thesis [5].
- Co-chair of the 4th workshop on Spatial Stochastic Modeling of Wireless Networks (SpaSWiN 2008) http://www.spaswin.org/2008/, in conjunction with WiOpt 2008 http://www.wiopt.org/wiopt08/.
- Presentations at the following conferences:
  - WiOpt 2008 (March/April, Berlin, Germany; http://www.wiopt.org/wiopt08/).
  - IEEE INFOCOM 2008 (Phoenix, Arizona, USA, April 2008; http://www.comsoc.org/confs/infocom/2008/).
  - 10th Conference on Probability (Będlewo, Poland, May 2008; http://www.mimuw.edu.pl/~probab/),
  - Second Wroclaw Workshop on Stochastic Geometry and Stochastic Models (University of Wroclaw, Poland, October 2008; http://www.math.uni.wroc.pl/tok/conferences/081109_second_workshop_stoch_geom.php).

Giovanna Carofiglio

- Member of the program committee of CoNext 2008 (Shadow TPC).
- Presentations at the following conferences:
  - IEEE INFOCOM 2008 (Phoenix, Arizona, USA, April 2008; http://www.comsoc.org/confs/infocom/2008/).
  - Symposium sur les perspectives en modélisation et évaluation des systèmes et réseaux informatiques Model35 (Rocquencourt, France, April 2008; http://www-rocq.inria.fr/model35/).

Bruno Kauffmann

- Participation in the Internet Measurement Conference (IMC) (Vouliagmeni, Greece, October, 2008; http://www.imconf.net/imc-2008/cfp.html).

Marc Lelarge

- Member of the program committee of Euro-NF conference: NetCoop 2008 (Paris, September, http://lia.univ-avignon.fr/netcoop2008).
- Organiser of the second Young European Queueing Theorists conference: YEQT(Eindhoven, December, http://www.eurandom.tue.nl/workshops/2008/YEQTII/YEQT_main.htm).
- Presentations at the following conferences:
  - ACM SIGMETRICS 2008 (Annapolis, June, http://www1.cs.columbia.edu/~sigmet08/).
  - ACM SIGCOMM workshop: NetEcon’08 (Seattle, August, http://conferences.sigcomm.org/sigcomm/2008/workshops/netecon/index.php).

    * Conference of the European Association for Research in Industrial Economics (Toulouse, September, http://www.earie08-toulouse.org/).
    * EURONF conference: NetCoop'08 (Paris, September, http://lia.univ-avignon.fr/netcoop2008).
    * The 4th International Workshop On Internet And Network Economics: WINE 2008 (Shanghai, December, http://www.se.cuhk.edu.hk/~wine2008/).
- Participation in the following conferences:
    * ACM SIGCOMM 2008 (Seattle, August, http://conferences.sigcomm.org/sigcomm/2008/).
- Presentation at the following seminars:
    * Young European Probabilists V: Statistical Mechanics on Random Structures, EURANDOM, (Eindhoven, March, http://www.eurandom.tue.nl/workshops/2008/YEPV-r/YepVmain.htm).
    * ARC Popeye-GameComp: Game Theory for Analysis and Optimization of Computer Systems, Université de Grenoble, (May, http://www.eurandom.tue.nl/workshops/2008/YEPV-r/YepVmain.htm).
    * Meeting on Complexity and Networks: Epidemic Spreading and Networks, Imperial College London, (October, http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/eventssummary/event_27-8-2008-10-30-7?eventid=42874).
    * seminars in univerities: HyNet Advanced Network Colloquium Series (University of Maryland), Université de Technologie Compiègne, LIP Seminar (Lyon), UC Berkeley Networking seminar.

Frédéric Morlot

- Presentation at the following seminars:
    * TEMPO seminar at Orange Labs (organized by Thomas Bonald).
    * Stochastic Geometry Seminar at Orange Labs (organized by Catherine Gloaguen and Volker Schmidt).

Justin Salez

- Prepared and obtained in 2008 the *Agrégation* in mathematics and computer science.
- In charge of both mathematics and computer science tutorials in *Classes Préparatoires aux Grandes Écoles (MPSI)*, Lycée Henri IV, Paris, 2008.

Yogeshwaran Dhandapani

- Presentations at the following conferences
    * German Open Conference in Probability and Statistics (Aachen, March 2008 http://gocps2008.rwth-aachen.de/).
    * Young European Probabilists Workshop (Eindhoven, March 2008; http://www.eurandom.tue.nl/workshops/2008/YEPV-r/YepVmain.htm).
    * Second Wroclaw Workshop on Stochastic Geometry and Stochastic Models (University of Wroclaw, Poland, October 2008; http://www.math.uni.wroc.pl/tok/conferences/081109_second_workshop_stoch_geom.php).

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

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

Year Publications

Doctoral Dissertations and Habilitation Theses

[5] B. BŁASZCZYSZYN. *Stochastic Geometry Methods and their Applications in Queueing and Telecommunications*, Habilitation à Diriger des Recherches, Department of Mathematics and Computer Science, University of Wrocław, Poland, October 2008.

[6] G. CAROFIGLIO. *Flow-level Stochastic Analysis and Fluid Modelling of TCP/IP networks*, Ph. D. Thesis, Politecnico di Torino and Telecom Paris Tech, April 2008.

[7] H. Q. NGUYEN. *Réseaux Sans Fil Hybrides WiFi–WiMax*, Ph. D. Thesis, Telecom Paris Tech, March 2008.

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[8] D. ALDOUS, C. BORDENAVE, M. LELARGE. *Near-Minimal Spanning Trees: a Scaling Exponent in Probability Models*, in "Annales de l'Institut Henri Poincaré (B)", vol. 44, n^o 5, 2008, p. 962-976.

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