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Activity Report 2015

Project-Team DYOGENE

Dynamics of Geometric Networks

IN COLLABORATION WITH: Département d'Informatique de l'Ecole Normale Supérieure

RESEARCH CENTER
Paris - Rocquencourt

THEME
Networks and Telecommunications

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Project-Team DYOGENE

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7.9. - Graph theory

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4.2. - Renewable energy production
6.2.2. - Radio technology
6.3.4. - Social Networks

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2. Overall Objectives

2.1. Overall Objectives

A large number of real-world structures and phenomena can be described by networks: separable elements with connections between certain pairs of them. Among such networks, the best known and the most studied in computer science is the Internet. Moreover, the Internet (as the physical underlying network) gives itself rise to many new networks, like the networks of hyperlinks, Internet based social networks, distributed data bases, codes on graphs, local interactions of wireless devices. These huge networks pose exciting challenges for the mathematician and the mathematical theory of networks faces novel, unconventional problems. For example, very large networks cannot be completely known, and data about them can be collected only by indirect means like random local sampling or by monitoring the behavior of various aggregated quantities.

The scientific focus of DYOGENE is on geometric network dynamics arising in communications. By geometric networks we understand networks with a nontrivial, discrete or continuous, geometric definition of the existence of links between the nodes. In stochastic geometric networks, this definition leads to random graphs or stochastic geometric models. A first type of geometric network dynamics is that where the nodes or the links change over time according to an exogeneous dynamics (e.g. node motion and geometric definition of the links). We will refer to this as dynamics of geometric networks below. A second type is that where links and/or nodes are fixed but harbor local dynamical systems (in our case, stemming from e.g. information theory, queuing theory, social and economic sciences). This will be called dynamics on geometric networks. A third type is that where the dynamics of the network geometry and the local dynamics interplay. Our motivations for studying these systems stem from many fields of communications where they play a central role, and in particular: message passing algorithms; epidemic algorithms; wireless networks and information theory; device to device networking; distributed content delivery; social and economic networks.

3. Research Program

3.1. Network Calculus

Network calculus [58] is a theory for obtaining deterministic upper bounds in networks that has been developed by R. Cruz [51], [52]. From the modelling point of view, it is an algebra for computing and propagating constraints given in terms of envelopes. A flow is represented by its cumulative function $R(t)$ (that is, the amount of data sent by the flow up to time t). A constraint on a flow is expressed by an arrival curve $\alpha(t)$ that gives an upper bound for the amount of data that can be sent during any interval of length t. Flows cross service elements that offer guarantees on the service. A constraint on a service is a service curve $\beta(t)$ that is used to compute the amount of data that can be served during an interval of length t. It is also possible to define in the same way minimal arrival curves and maximum service curves. Then such constraints envelop the processes and the services. Network calculus enables the following operations:

- computing the exact output cumulative function or at least bounding functions;
- computing output constraints for a flow (like an output arrival curve);
- computing the remaining service curve (that is, the service that of not used by the flows crossing a server);
- composing several servers in tandem;

• giving upper bounds on the worst-case delay and backlog (bounds are tight for a single server or a single flow).
The operations used for this are an adaptation of filtering theory to $(\min, +)$: $(\min, +)$ convolution and deconvolution, sub-additive closure.

We investigate the complexity of computing exact worst-case performance bounds in network calculus and to develop algorithms that present a good trade off between algorithmic efficiency and accuracy of the bounds.

3.2. Perfect Simulation

Simulation approaches can be used to efficiently estimate the stationary behavior of Markov chains by providing independent samples distributed according to their stationary distribution, even when it is impossible to compute this distribution numerically.

The classical Markov Chain Monte Carlo simulation techniques suffer from two main problems:
• The convergence to the stationary distribution can be very slow, and it is in general difficult to estimate;
• Even if one has an effective convergence criterion, the sample obtained after any finite number of iterations is biased.

To overcome these issues, Propp and Wilson [60] have introduced a perfect sampling algorithm (PSA) that has later been extended and applied in various contexts, including statistical physics [55], stochastic geometry [57], theoretical computer science [49], and communications networks [48], [54] (see also the annotated bibliography by Wilson [64]).

Perfect sampling uses coupling arguments to give an unbiased sample from the stationary distribution of an ergodic Markov chain on a finite state space $\mathcal{X}$. Assume the chain is given by an update function Φ and an i.i.d. sequence of innovations $(U_n)_{n\in\mathbb{Z}}$, so that

$$X_{n+1} = \Phi(X_n, U_{n+1}). \tag{1}$$

The algorithm is based on a backward coupling scheme: it computes the trajectories from all $x \in \mathcal{X}$ at some time in the past $t = -T$ until time $t = 0$, using the same innovations. If the final state is the same for all trajectories (i.e. $|\{\Phi(x, U_{-T+1}, ..., U_0) \,:\, x \in \mathcal{X}\}| = 1$, where $\Phi(x, U_{-T+1}, ..., U_0) := \Phi(\Phi(x, U_{-T+1}), U_{-T+2}, ..., U_0)$ is defined by induction on T), then we say that the chain has globally coupled and the final state has the stationary distribution of the Markov chain. Otherwise, the simulations are started further in the past.

Any ergodic Markov chain on a finite state space has a representation of type (1) that couples in finite time with probability 1, so Propp and Wilson's PSA gives a "perfect" algorithm in the sense that it provides an *unbiased* sample in *finite time*. Furthermore, the stopping criterion is given by the coupling from the past scheme, and knowing the explicit bounds on the coupling time is not needed for the validity of the algorithm.

However, from the computational side, PSA is efficient only under some monotonicity assumptions that allow reducing the number of trajectories considered in the coupling from the past procedure only to extremal initial conditions. Our goal is to propose new algorithms solving this issue by exploiting semantic and geometric properties of the event space and the state space.

3.3. Stochastic Geometry

Stochastic geometry [63] 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. Initially its development was stimulated by applications to biology, astronomy and material sciences. Nowadays it is also widely used in image analysis. It 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 (user locations) of the Euclidean plane (e.g., a 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). Further classical models include shot noise processes and random tessellations. Our research consists of analyzing these models with the aim of better understanding wireless communication networks in order to predict and control various network performance metrics. The models require using techniques from stochastic geometry and related fields including point processes, spatial statistics, geometric probability, percolation theory.

3.4. Information Theory

Classical models of stochastic geometry (SG) are not sufficient for analyzing wireless networks as they ignore the specific nature of radio channels.

Consider a wireless communication network made of a collection of nodes which in turn can be transmitters or receivers. At a given time, some subset of this collection of nodes simultaneously transmit, each toward its own receiver. Each transmitter–receiver pair in this snapshot requires its own wireless link. For each such wireless link, the power of the signal received from the link transmitter is jammed by the powers of the signals received from the other transmitters. Even in the simplest model where the power radiated from a point decays in some isotropic way with Euclidean distance, the geometry of the location of nodes plays a key role within this setting since it determines the signal to interference and noise ratio (SINR) at the receiver of each such link and hence the possibility of establishing simultaneously this collection of links at a given bit rate, as shown by information theory (IT). In this definition, the interference seen by some receiver is the sum of the powers of the signals received from all transmitters excepting its own. The SINR field, which is of an essentially geometric nature, hence determines the connectivity and the capacity of the network in a broad sense. The essential point here is that the characteristics and even the feasibilities of the radio links that are simultaneously active are strongly interdependent and determined by the geometry. Our work is centered on the development of an IT-aware stochastic geometry addressing this interdependence.

3.5. The Cavity Method for Network Algorithms

The cavity method combined with geometric networks concepts has recently led to spectacular progresses in digital communications through error-correcting codes. More than fifty years after Shannon's theorems, some coding schemes like turbo codes and low-density parity-check codes (LDPC) now approach the limits predicted by information theory. One of the main ingredients of these schemes is message-passing decoding strategies originally conceived by Gallager, which can be seen as direct applications of the cavity method on a random bipartite graph (with two types of nodes representing information symbols and parity check symbols, see [61]).

Modern coding theory is only one example of application of the cavity method. The concepts and techniques developed for its understanding have applications in theoretical computer science and a rich class of *complex systems*, in the field of networking, economics and social sciences. The cavity method can be used both for the analysis of randomized algorithms and for the study of random ensembles of computational problems representative real-world situations. In order to analyze the performance of algorithms, one generally defines a family of instances and endows it with a probability measure, in the same way as one defines a family of samples in the case of spin glasses or LDPC codes. The discovery that the hardest-to-solve instances, with all existing algorithms, lie close to a *phase transition* boundary has spurred a lot of interest. Theoretical physicists suggest that the reason is a structural one, namely a change in the geometry of the set of solutions related to the *replica symmetry breaking* in the cavity method. Phase transitions, which lie at the core of statistical physics, also play a key role in computer science [62], signal processing [53] and social sciences [56]. Their analysis is a major challenge, that may have a strong impact on the design of related algorithms.

We develop mathematical tools in the theory of discrete probabilities and theoretical computer science in order to contribute to a rigorous formalization of the cavity method, with applications to network algorithms, statistical inference, and at the interface between computer science and economics (EconCS).

3.6. Statistical Learning

Sparse graph structures are useful in a number of information processing tasks where the computational problem can be described as follows: infer the values of a large collection of random variables, given a set of constraints or observations, that induce relations among them. Similar design ideas have been proposed in sensing and signal processing and have applications in coding [50], network measurements, group testing or multi-user detection. While the computational problem is generally hard, sparse graphical structures lead to low-complexity algorithms that are very effective in practice. We develop tools in order to contribute to a precise analysis of these algorithms and of their gap to optimal inference which remains a largely open problem.

A second line of activities concerns the design of protocols and algorithms enabling a transmitter to learn its environment (the statistical properties of the channel quality to the corresponding receiver, as well as their interfering neighbouring transmitters) so as to optimise their transmission strategies and to fairly and efficiently share radio resources. This second objective calls for the development and use of machine learning techniques (e.g. bandit optimisation).

4. Application Domains

4.1. Wireless Networks

Wireless networks can be efficiently modelled as dynamic stochastic geometric networks. Their analysis requires taking into account, in addition to their geometric structure, the specific nature of radio channels and their statistical properties which are often unknown a priori, as well as the interaction through interference of the various individual point-to-point links. Established results contribute in particular to the development of network dimensioning methods and some of them are currently used in Orange internal tools for network capacity calculations.

4.2. Embedded Networks

Critical real-time embedded systems (cars, aircrafts, spacecrafts) are nowadays made up of multiple computers communicating with each other. The real-time constraints typically associated with operating systems now extend to the networks of communication between sensors/actuators and computers, and between the computers themselves. Once a media is shared, the time between sending and receiving a message depends not only on technological constraints, but also, and mainly from the interactions between the different streams of data sharing the media. It is therefore necessary to have techniques to guarantee maximum network delays, in addition to local scheduling constraints, to ensure a correct global real-time behaviour to distributed applications/functions.

Moreover, pessimistic estimate may lead to an overdimensioning of the network, which involves extra weight and power consumption. In addition, these techniques must be scalable. In a modern aircraft, thousands of data streams share the network backbone. Therefore algorithm complexity should be at most polynomial.

4.3. Distributed Content Delivery Networks

A content distribution network (CDN) is a globally distributed network of proxy servers deployed in multiple data centers. The goal of a CDN is to serve content to end-users with high availability and high performance. CDNs serve a large fraction of the Internet content today, including web objects (text, graphics and scripts), downloadable objects (media files, software, documents), applications (e-commerce, portals), live streaming media, on-demand streaming media, and social networks. In [33], we address the problem of content replication in large distributed content delivery networks.

4.4. Probabilistic Algorithms for Renewable Integration in Smart grid

This reserach is developed by the Associate Team PARIS; http://www.di.ens.fr/~busic/PARIS/.

Challenges to Renewable Integration. With greater penetration of renewables, there is a need for tremendous shock absorbers to smooth the volatility of renewable power. An example is the balancing reserves obtained today from fossil-fuel generators, that ramp up and down their power output in response to a command signal from a grid balancing authority - an example of an ancillary service. In the absence of large, expensive batteries, we may have to increase our inventory of responsive fossil-fuel generators, negating the environmental benefits of renewable energy.

The goal of our research is to demonstrate that we do not need to rely entirely on expensive batteries or fast-responding fossil fuel generators to track regulation signals or balancing reserves. There is enormous flexibility in the power consumption of the majority of electric loads. This flexibility can be exploited to create "virtual batteries". The best example of this is the heating, ventilation, and air conditioning (HVAC) system of a building: There is no perceptible change to the indoor climate if the airflow rate is increased by 10% for 20 minutes, and decreased by 10% for the next 20 minutes. Power consumption deviations follow the airflow deviations closely, but indoor temperature will be essentially constant.

A starting point in our research is the fact that many of the ancillary services needed today are defined by a power deviation reference signal that has zero mean. Examples are PJM's RegD signal, or BPA's balancing reserves [1]. We have demonstrated that loads can be classified based on the frequency bandwidth of ancillary service that they can offer. If demand response from loads respects these frequency limitations, it is possible to obtain highly reliable ancillary service to the grid, while maintaining strict bounds on the quality of service (QoS) delivered by each load [23].

Control Design with Local Intelligence at the Loads. An emphasis of our research is the creation of Smart Communities to complement a Smart Grid: intelligence is created at each load in the community. For example, a water heater may be equipped with a simple device that measures the grid frequency – a measure of power mismatch that is regulated to stabilize the power grid. Larger loads may receive a signal from a balancing authority.

A challenge in residential communities is that many loads are either on or off. How can an on/off load track the continuously varying regulation signal broadcast by a grid operator? The answer proposed in our recent work is based on probabilistic algorithms: A single load cannot track a regulation signal such as the balancing reserves. A collection of loads can, provided they are equipped with local control. The value of probabilistic algorithms is that a) they can be designed with minimal communication, b) they avoid synchronization of load responses, and c) it is shown in our recent work that they can be designed to simplify control at the grid level (see the survey [23] and [20], [30]). Other researchers have introduced randomization (see in particular the thesis of J. Mathieu [59]), but without the use of "local intelligence" (distributed control).

4.5. Algorithms for finding communities

In the study of complex networks, a network is said to have community structure if the nodes of the network can be easily grouped into (potentially overlapping) sets of nodes such that each set of nodes is densely connected internally. Community structures are quite common in real networks. Social networks include community

[1] BPA balancing authority. Online, http://tinyurl.com/BPAgenload http://tinyurl.com/BPAbalancing.

groups (the origin of the term, in fact) based on common location, interests, occupation, etc. Metabolic networks have communities based on functional groupings. Citation networks form communities by research topic. Being able to identify these sub-structures within a network can provide insight into how network function and topology affect each other. We propose several algorithms for this problem and extensions [46], [36], [27], [37]

5. Highlights of the Year

5.1. Highlights of the Year

Stochastic networks and stochastic geometry conference dedicated to François Baccelli on his 60th birthday

This three day event http://www.di.ens.fr/~blaszczy/FB60/ brought together about twenty invited talks given by leading researchers working on modeling and performance evaluation of computer/communication systems. Mathematical foundations of their work involve, but are not limited to, wireless stochastic geometry, information theory, discrete event dynamical systems, max-plus algebra, stationary-ergodic framework for stochastic networks. It was a wonderful occasion to celebrate the 60th birthday of François Baccelli, who has inspired the development of this field for almost 40 years. The organizers are grateful to all speakers and participants.

Awards

- Ana Busic and Sean Meyn received jointly a Google Faculty Research Award for their research on Distributed Control for Renewable Integration in Smart Communities.
  http://googleresearch.blogspot.com/2015/02/google-faculty-research-awards-winter.html

The Applied Probability Society of INFORMS presents a 2015 Best Publication Award to Mohsen Bayati, Marc Lelarge and Andrea Montanari for their paper

BEST PAPER AWARD:

[5]
M. BAYATI, M. LELARGE, A. MONTANARI. *Universality in polytope phase transitions and message passing algorithms*, in "Annals of Applied Probability", April 2015, vol. 25, n^{o} 2, pp. 753-822 [*DOI :* 10.1214/14-AAP1010], https://hal.archives-ouvertes.fr/hal-01254901

6. New Software and Platforms

6.1. CloNES

CLOsed queueing Networks Exact Sampling
FUNCTIONAL DESCRIPTION

Clones is a Matlab toolbox for exact sampling of closed queueing networks.

- Participant: Christelle Rovetta
- Contact: Christelle Rovetta
- URL: http://www.di.ens.fr/~rovetta/Clones/index.html

7. New Results

7.1. Evaluation and optimization of the quality of service perceived by mobile users for new services in cellular networks

The goal of this thesis[1] defended in 2015 is to develop tools and methods for the evaluation of the QoS (Quality of Service) perceived by users, as a function of the traffic demand, in modern wireless cellular networks. This complex problem, directly related to network dimensioning, involves modeling dynamic processes at several time-scales, which due to their randomness are amenable to probabilistic formalization. Firstly, on the ground of information theory, we capture the performance of a single link between a base station and a user in the context of a cellular network with orthogonal channels and MIMO technology. We prove and use some lower bounds of the information-theoretic ergodic capacity of such a link, which account also for the fast channel variability caused by multi-path propagation. These bounds give robust basis for further user QoS evaluation. Next, one considers several (possibly mobile) users, arriving in the network and requesting some service from it. We consider variable (elastic) bit-rate services, in which transmissions of some amounts of data are realized in a best-effort manner, or constant bit-rate services, in which a certain transmission rate needs to be maintained during requested times. On the ground of queuing theory, one captures this traffic demand and service process using appropriate (multi-class) processor sharing (PS) or loss models. In this thesis, we adapt existing PS models and develop a new loss model for wireless streaming traffic, in which the aforementioned information-theoretic capacities of single links describe the instantaneous user service rates. The multi-class models are used to capture the spatial heterogeneity of user channels, which depends on the user geographic locations and propagation shadowing phenomenon. Finally, on top of the queueing-theoretic processes, one needs to consider a multi-cellular network, whose base stations are not necessarily regularly placed, and whose geometry is further perturbed by the shadowing phenomenon. We address this randomness aspect by using some models from stochastic geometry, notably Poisson point processes and Palm formalism applied to the typical cell of the network. Applying the above three-fold approach, supposed to represent all crucial mechanisms and engineering parameters of cellular networks (such as LTE), we establish some macroscopic relations between the traffic demand and the user QoS metrics for some elastic and constant bit-rate services. These relations are mostly obtained in a semi-analytic way, i.e., they only involve static simulations of a Poisson point process (modeling the locations of base stations) in order to evaluate its characteristics which are not amenable to analytic expressions. More precisely, regarding the data traffic (the elastic bit-rate service), we capture the inter-cell interference, making the PS queue models of individual cells dependent, via some system of cell-load equations. These equations allow one to determine the mean user throughput, the mean number of users and the mean cell load in a large network, as a function of the traffic demand. The spatial distribution of these QoS metrics in the network is also studied. We validate our approach by comparing the obtained results with those measured from live-network traces. We observe a remarkably good agreement between the model predictions and the statistical data collected in several deployment scenarios. Regarding constant bit-rate services, we propose a new stochastic model to evaluate the frequency and the number of interruptions during real-time streaming calls in function of user radio conditions. Despite some fundamental similarities with the classical Erlang loss model, a more adequate model was required for in this case, where the denial of service is not definitive for a given call: it takes the form of, hopefully short, interruptions or outage periods. Our model allows one to take into account realistic implementations of the considered streaming service. We use it to study the quality of service metrics in function of user radio conditions in LTE networks. All established results contribute to the development of network dimensioning methods and are currently used in Orange internal tools for network capacity calculations.

7.2. Interference and SINR coverage in spatial non-slotted Aloha networks

In [9] we propose two analytically tractable stochastic-geometric models of interference in ad-hoc networks using pure (non-slotted) Aloha as the medium access. In contrast the slotted model, the interference in pure Aloha may vary during the transmission of a tagged packet. We develop closed form expressions for the

Laplace transform of the empirical average of the interference experienced during the transmission of a typical packet. Both models assume a power-law path-loss function with arbitrarily distributed fading and feature configurations of transmitters randomly located in the Euclidean plane according to a Poisson point process. Depending on the model, these configurations vary over time or are static. We apply our analysis of the interference to study the Signal-to-Interference-and-Noise Ratio (SINR) outage probability for a typical transmission in pure Aloha. The results are used to compare the performance of non-slotted Aloha to the slotted one, which has almost exclusively been previously studied in the same context of mobile ad-hoc networks.

7.3. Random linear multihop relaying in a general field of interferers using spatial Aloha

In [10] we study, as a basic model, a stationary Poisson pattern of nodes on a line embedded in an independent planar Poisson field of interfering nodes. Assuming slotted Aloha and the signal-to-interference-and-noise ratio capture condition, with the usual power-law path loss model and Rayleigh fading, we explicitly evaluate several local and end-to-end performance characteristics related to the nearest-neighbor packet relaying on this line, and study their dependence on the model parameters (the density of relaying and interfering nodes, Aloha tuning and the external noise power). Our model can be applied in two cases: the first use is for vehicular ad-hoc networks, where vehicles are randomly located on a straight road. The second use is to study a typical route traced in a (general) planar ad-hoc network by some routing mechanism. The approach we have chosen allows us to quantify the non-efficiency of long-distance routing in pure ad-hoc networks and evaluate a possible remedy for it in the form of additional fixed relaying nodes, called road-side units in a vehicular network. It also allows us to consider a more general field of interfering nodes and study the impact of the clustering of its nodes the routing performance. As a special case of a field with more clustering than the Poison field, we consider a Poisson-line field of interfering nodes, in which all the nodes are randomly located on random straight lines. The comparison to our basic model reveals a paradox: clustering of interfering nodes decreases the outage probability of a single (typical) transmission on the route, but increases the mean end-to-end delay.

7.4. Studying the SINR process of the typical user in Poisson networks by using its factorial moment measures

Based on a stationary Poisson point process, a wireless network model with random propagation effects (shadowing and/or fading) is considered in [8] in order to examine the process formed by the signal-to-interference-plus-noise ratio (SINR) values experienced by a typical user with respect to all base stations in the down-link channel. This SINR process is completely characterized by deriving its factorial moment measures, which involve numerically tractable, explicit integral expressions. This novel framework naturally leads to expressions for the k-coverage probability, including the case of random SINR threshold values considered in multi-tier network models. While the k-coverage probabilities correspond to the marginal distributions of the order statistics of the SINR process, a more general relation is presented connecting the factorial moment measures of the SINR process to the joint densities of these order statistics. This gives a way for calculating exact values of the coverage probabilities arising in a general scenario of signal combination and interference cancellation between base stations. The presented framework consisting of mathematical representations of SINR characteristics with respect to the factorial moment measures holds for the whole domain of SINR and is amenable to considerable model extension.

7.5. Performance laws of large heterogeneous cellular networks

In [25] we propose a model for heterogeneous cellular networks assuming a space-time Poisson process of call arrivals, independently marked by data volumes, and served by different types of base stations (having different transmission powers) represented by the superposition of independent Poisson processes on the plane. Each station applies a processor sharing policy to serve users arriving in its vicinity, modeled by the Voronoi cell perturbed by some random signal propagation effects (shadowing). Users' peak service rates depend on their signal-to-interference-and-noise ratios (SINR) with respect to the serving station. The mutual-dependence of the cells (due to the extra-cell interference) is captured via some system of cell-load equations impacting the spatial distribution of the SINR. We use this model to study in a semi-analytic way (involving only static simulations, with the temporal evolution handled by the queuing theoretic results) network performance metrics (cell loads, mean number of users) and the quality of service perceived by the users (mean throughput) served by different types of base stations. Our goal is to identify macroscopic laws regarding these performance metrics, involving averaging both over time and the network geometry. The reveled laws are validated against real field measurement in an operational network.

7.6. Wireless networks appear Poissonian due to strong shadowing

Geographic locations of cellular base stations sometimes can be well fitted with spatial homogeneous Poisson point processes. In [7] we make a complementary observation: In the presence of the log-normal shadowing of sufficiently high variance, the statistics of the propagation loss of a single user with respect to different network stations are invariant with respect to their geographic positioning, whether regular or not, for a wide class of empirically homogeneous networks. Even in perfectly hexagonal case they appear as though they were realized in a Poisson network model, i.e., form an inhomogeneous Poisson point process on the positive half-line with a power-law density characterized by the path-loss exponent. At the same time, the conditional distances to the corresponding base stations, given their observed propagation losses, become independent and log-normally distributed, which can be seen as a decoupling between the real and model geometry. The result applies also to Suzuki (Rayleigh-log-normal) propagation model. We use Kolmogorov-Smirnov test to empirically study the quality of the Poisson approximation and use it to build a linear-regression method for the statistical estimation of the value of the path-loss exponent.

7.7. What frequency bandwidth to run cellular network in a given country? - a downlink dimensioning problem

In [26] we propose an analytic approach to the frequency bandwidth dimensioning problem, faced by cellular network operators who deploy/upgrade their networks in various geographical regions (countries) with an inhomogeneous urbanization. We present a model allowing one to capture fundamental relations between users' quality of service parameters (mean downlink throughput), traffic demand, the density of base station deployment, and the available frequency bandwidth. These relations depend on the applied cellular technology (3G or 4G impacting user peak bit-rate) and on the path-loss characteristics observed in different (urban, sub-urban and rural) areas. We observe that if the distance between base stations is kept inversely proportional to the distance coefficient of the path-loss function, then the performance of the typical cells of these different areas is similar when serving the same (per-cell) traffic demand. In this case, the frequency bandwidth dimensioning problem can be solved uniformly across the country applying the mean cell approach proposed in [Blaszczyszyn et al. WiOpt2014]. We validate our approach by comparing the analytical results to measurements in operational networks in various geographical zones of different countries.

7.8. Optimal Geographic Caching In Cellular Networks

In [24] we consider the problem of an optimal geographic placement of content in wireless cellular networks modelled by Poisson point processes. Specifically, for the typical user requesting some particular content and whose popularity follows a given law (e.g. Zipf), we calculate the probability of finding the content cached in one of the base stations. Wireless coverage follows the usual signal-to-interference-and noise ratio (SINR) model, or some variants of it. We formulate and solve the problem of an optimal randomized content placement policy, to maximize the user's hit probability. The result dictates that it is not always optimal to follow the standard policy "cache the most popular content, everywhere". In fact, our numerical results regarding three different coverage scenarios, show that the optimal policy significantly increases the chances of hit under high-coverage regime, i.e., when the probabilities of coverage by more than just one station are high enough.

7.9. Spatial distribution of the SINR in Poisson cellular networks with sector antennas

In [6] we consider a model of cellular networks where the base station locations constitute a Poisson point process and each base station is equipped with three sectorial antennas is proposed. This model permits to study the spatial distribution of the SINR in the downlink. In particular, this distribution is shown to be insensitive to the distribution of antenna azimuths. Moreover, the effect of horizontal sectorisation is shown to be equivalent to that of shadowing. Assuming ideal vertical antenna pattern, an explicit expression of the Laplace transform of the inverse of SINR is given. The model is validated by comparing its results to measurements in an operational network. It is observed numerically that, in the case of dense urban regions where interference is preponderant, one may neglect the effect of the vertical sectorization when calculating the distribution of the SINR, which provides considerable tractability. Combined with queuing theory results, the SINR's distribution permits to express the user's quality of service as function of the traffic demand. This permits in particular to operators to predict the required investments to face the continual increase of traffic demand.

7.10. Theoretical expression of link performance in OFDM cellular networks with MIMO compared to simulation and measurements

The objective of [19] is to establish a theoretical expression of the link performance in the downlink of a multiple input multiple output (MIMO) cellular network and compare it to the real Long-Term Evolution (LTE) performance. In order to account for the interference, we prove that the worst additive noise process in the MIMO context is the white Gaussian one. Based on this theoretical result, we build an analytic expression of the link performance in LTE cellular networks with MIMO. We study also the minimum mean square error (MMSE) scheme currently implemented in the field, as well as its improvement MMSE-SIC (successive interference cancellation) known to achieve the MIMO capacity. Comparison to simulation results as well as to measurements in the field shows that the theoretical expression predicts well practical link performance of LTE cellular networks. This theoretical expression of link performance is the basis of a global analytic approach to the evaluation of the quality of service perceived by the users in the long run of their arrivals and departures.

7.11. Information Theory: Boolean model in the Shannon Regime

In a paper accepted for publication in the Journal of Applied Probability, F. Baccelli and V. Anantharam consider a family of Boolean models, indexed by integers $n \geq 1$. The n-th model features a Poisson point process in $\mathbb{R}^n$ of intensity $e^{n\rho_n}$ and balls of independent and identically distributed radii distributed like $\overline{X}_n\sqrt{n}$. Assume that $\rho_n \to \rho$ as $n \to \infty$, and that $\overline{X}_n$ satisfies a large deviations principle. It is shown that there then exist three deterministic thresholds: τ_d the degree threshold; τ_p the percolation probability threshold; and τ_v the volume fraction threshold, such that asymptotically as n tends to infinity, we have the following features. (i) For $\rho < \tau_d$, almost every point is isolated, namely its ball intersects no other ball; (ii) for $\tau_d < \rho < \tau_p$, the mean number of balls intersected by a typical ball converges to infinity and nevertheless there is no percolation; (iii) for $\tau_p < \rho < \tau_v$, the volume fraction is 0 and nevertheless percolation occurs; (iv) for $\tau_d < \rho < \tau_v$, the mean number of balls intersected by a typical ball converges to infinity and nevertheless the volume fraction is 0; (v) for $\rho > \tau_v$, the whole space covered. The analysis of this asymptotic regime is motivated by problems in information theory, but it could be of independent interest in stochastic geometry. The relations between these three thresholds and the Shannon–Poltyrev threshold are discussed.

7.12. Stochastic Geometry: Wireless Modeling

In an Infocom'15 paper, F. Baccelli and X. Zhang (Qualcomm) have introduced an analytically tractable stochastic geometry model for urban wireless networks, where the locations of the nodes and the shadowing are highly correlated and different path loss functions can be applied to line-of-sight (LOS) and non-line-of-sight (NLOS) links.

Using a distance-based LOS path loss model and a blockage (shadowing)-based NLOS path loss model, one can derive the distribution of the interference observed at a typical location and the joint distribution at different locations of the network. When applied to cellular networks, this model leads to tractable coverage probabilities (SINR distribution) expressions. This model captures important features of urban wireless networks, which were difficult to analyze using existing models.

This model was lately extended in a joint work by the same authors and Robert Heath (UT Austin) in a paper presented at IEEE Globecom'15 where it received the best paper award.

7.13. Information Theory: SIMO

In a paper to be published in IEEE Transactions of Information Theory, F. Baccelli, N. Lee and Robert Heath consider large random wireless networks where transmit-and-receive node pairs communicate within a certain range while sharing a common spectrum. By modeling the spatial locations of nodes as Poisson point processes, analytical expressions for the ergodic spectral efficiency of a typical node pair are derived as a function of the channel state information available at a receiver (CSIR) in terms of relevant system parameters: the density of communication links, the number of receive antennas, the path loss exponent, and the operating signal-to-noise ratio. One key finding is that when the receiver only exploits CSIR for the direct link, the sum spectral efficiency increases linearly with the density, provided the number of receive antennas increases as a certain super-linear function of the density. When each receiver exploits CSIR for a set of dominant interfering links in addition to that of the direct link, the sum spectral efficiency in creases linearly with both the density and the path loss exponent if the number of antennas is a linear function of the density. This observation demonstrates that having CSIR for dominant interfering links provides an order gain in the scaling law. It is also shown that this linear scaling holds for direct CSIR when incorporating the effect of the receive antenna correlation, provided that the rank of the spatial correlation matrix scales super-linearly with the density. These scaling laws are derived from integral representations of the distribution of the Signal to Interference and Noise Ratio, which are of independent interest and which in turn derived from stochastic geometry and more precisely from the theory of Shot Noise fields.

7.14. Theory of point processes

In a joint work with Mir-Omid Haji-Mirsadeghi, Sharif University, Department of Mathematics, F. Baccelli studied a class of non-measure preserving dynamical systems on counting measures called point-maps. This research introduced two objects associated with a point map f acting on a stationary point process Φ:

- The f-probabilities of Φ, which can be interpreted as the stationary regimes of the action of f on Φ. These probabilities are defined from the compactification of the action of the semigroup of point-map translations on the space of Palm probabilities. The f-probabilities of Φ are not always Palm distributions.
- The f-foliation of Φ, a partition of the support of Φ which is the discrete analogue of the stable manifold of f, i.e., the leaves of the foliation are the points of Φ with the same asymptotic fate for f. These leaves are not always stationary point processes. There always exists a point-map allowing one to navigate the leaves in a measure-preserving way.

Two papers on the matter available. The first one is under revision for Annals of Probability.

7.15. Cross-Technology Interference Mitigation in Body Area Networks: An Optimization Approach

In recent years, wearable devices and wireless body area networks have gained momentum as a means to monitor people's behavior and simplify their interaction with the surrounding environment, thus representing a key element of the body-to-body networking (BBN) paradigm. Within this paradigm, several transmission technologies, such as 802.11 and 802.15.4, that share the same unlicensed band (namely, the industrial, scientific, and medical band) coexist, dramatically increasing the level of interference and, in turn, negatively affecting network performance. In this paper, we analyze the cross-technology interference (CTI) caused by the utilization of different transmission technologies that share the same radio spectrum. We formulate an optimization model that considers internal interference, as well as CTI to mitigate the overall level of interference within the system, explicitly taking into account node mobility. We further develop three heuristic approaches to efficiently solve the interference mitigation problem in large-scale network scenarios. Finally, we propose a protocol to compute the solution that minimizes CTI in a distributed fashion. Numerical results show that the proposed heuristics represent efficient and practical alternatives to the optimal solution for solving the CTI mitigation (CTIM) problem in large-scale BBN scenarios.

7.16. Body-to-Body Area Networks

The ongoing evolution of wireless technologies has fostered the development of innovative network paradigms like the Internet of Things (IoT). Wireless Body Area Networks, and more specifically Body-to-Body Area Networks (BBNs), are emerging solutions for the monitoring of people's behavior and their interaction with the surrounding environment. These networks represent a key building block of the IoT paradigm. In BBNs several transmission technologies like 802.11 and 802.15.4 that share the same unlicensed band (namely the industrial, scientific and medical (ISM) radio band) coexist, increasing dramatically the level of interference and, in turn, negatively affecting network's performance. In [15], we investigate the Cross-Technology Interference Mitigation (CTIM) problem caused by the utilization of different transmission technologies that share the same radio spectrum, from a centralized and distributed point of view, respectively.

7.17. Exact Worst-Case Delay in FIFO-Multiplexing Feed-Forward Networks

In [12], we compute the actual worst-case end-to-end delay for a flow in a feed-forward network of FIFO-multiplexing service curve nodes, where flows are shaped by piecewise-affine concave arrival curves, and service curves are piecewise affine and convex. We show that the worst-case delay problem can be formulated as a mixed integer-linear programming problem, whose size grows exponentially with the number of nodes involved. Furthermore, we present approximate solution schemes to find upper and lower delay bounds on the worst-case delay. Both only require to solve just one linear programming problem, and yield bounds which are generally more accurate than those found in the previous work, which are computed under more restrictive assumptions.

7.18. Fast symbolic computation of the worst-case delay in tandem networks and applications

Computing deterministic performance guarantees is a defining issue for systems with hard real-time constraints, like reactive embedded systems. In [11], we use burst-rate constrained arrivals and rate-latency servers to deduce tight worst-case delay bounds in tandem networks under arbitrary multiplexing. We present a constructive method for computing the exact worst-case delay, which we prove to be a linear function of the burstiness and latencies; our bounds are hence symbolic in these parameters. Our algorithm runs in quadratic time in the number of servers. We also present an application of our algorithm to the case of stochastic arrivals and server capacities. For a generalization of the exponentially bounded burstiness (EBB) model, we deduce a polynomial-time algorithm for stochastic delay bounds that strictly improve the state-of-the-art separated flow analysis (SFA) type bounds.

7.19. Ancillary Service to the Grid Using Intelligent Deferrable Loads

Renewable energy sources such as wind and solar power have a high degree of unpredictability and time-variation, which makes balancing demand and supply challenging. One possible way to address this challenge is to harness the inherent flexibility in demand of many types of loads. Introduced in [20] is a technique for decentralized control for automated demand response that can be used by grid operators as ancillary service for maintaining demand-supply balance. A randomized control architecture is proposed, motivated by the need for decentralized decision making, and the need to avoid synchronization that can lead to large and detrimental spikes in demand. An aggregate model for a large number of loads is then developed by examining the mean field limit. A key innovation is a linear time-invariant (LTI) system approximation of the aggregate nonlinear model, with a scalar signal as the input and a measure of the aggregate demand as the output. This makes the approximation particularly convenient for control design at the grid level.

7.20. Spectral Decomposition of Demand-Side Flexibility for Reliable Ancillary Services in a Smart Grid

[23] describes a new way of thinking about demand-side resources to provide ancillary services to control the grid. It is shown that loads can be classified based on the frequency bandwidth of ancillary service that they can offer. If demand response from loads respects these frequency limitations, it is possible to obtain highly reliable ancillary service to the grid, while maintaining strict bounds on the quality of service (QoS) delivered by each load. It is argued that automated demand response is required for reliable control. Moreover, some intelligence is needed at demand response loads so that the aggregate will be reliable and controllable.

7.21. State Estimation for the Individual and the Population in Mean Field Control with Application to Demand Dispatch

[30] concerns state estimation problems in a mean field control setting. In a finite population model, the goal is to estimate the joint distribution of the population state and the state of a typical individual. The observation equations are a noisy measurement of the population. The general results are applied to demand dispatch for regulation of the power grid, based on randomized local control algorithms. In prior work by the authors it has been shown that local control can be carefully designed so that the aggregate of loads behaves as a controllable resource with accuracy matching or exceeding traditional sources of frequency regulation. The operational cost is nearly zero in many cases. The information exchange between grid and load is minimal, but it is assumed in the overall control architecture that the aggregate power consumption of loads is available to the grid operator. It is shown that the Kalman filter can be constructed to reduce these communication requirements, and to provide the grid operator with accurate estimates of the mean and variance of quality of service (QoS) for an individual load.

7.22. Perfect sampling of Jackson queueing networks

In [13], we consider open Jackson networks with losses with mixed finite and infinite queues and analyze the efficiency of sampling from their exact stationary distribution. We show that perfect sampling is possible, although the underlying Markov chain may have an infinite state space. The main idea is to use a Jackson network with infinite buffers (that has a product form stationary distribution) to bound the number of initial conditions to be considered in the coupling from the past scheme. We also provide bounds on the sampling time of this new perfect sampling algorithm for acyclic or hyper-stable networks. These bounds show that the new algorithm is considerably more efficient than existing perfect samplers even in the case where all queues are finite. We illustrate this efficiency through numerical experiments. We also extend our approach to variable service times and non-monotone networks such as queueing networks with negative customers.

7.23. Speeding up Glauber Dynamics for Random Generation of Independent Sets

The maximum independent set (MIS) problem is a well-studied combinatorial optimization problem that naturally arises in many applications, such as wireless communication, information theory and statistical mechanics. MIS problem is NP-hard, thus many results in the literature focus on fast generation of maximal independent sets of high cardinality. One possibility is to combine Gibbs sampling with coupling from the past arguments to detect convergence to the stationary regime. This results in a sampling procedure with time complexity that depends on the mixing time of the Glauber dynamics Markov chain. We propose in [38] an adaptive method for random event generation in the Glauber dynamics that considers only the events that are effective in the coupling from the past scheme, accelerating the convergence time of the Gibbs sampling algorithm.

7.24. Approximate optimality with bounded regret in dynamic matching models

In [29], we consider a dynamic matching model with random arrivals. In prior work, authors have proposed policies that are stabilizing, and also policies that are approximately finite-horizon optimal. This paper considers the infinite-horizon average-cost optimal control problem. A relaxation of the stochastic control problem is proposed, which is found to be a special case of an inventory model, as treated in the classical theory of Clark and Scarf. The optimal policy for the relaxation admits a closed-form expression. Based on the policy for this relaxation, a new matching policy is proposed. For a parameterized family of models in which the network load approaches capacity, this policy is shown to be approximately optimal, with bounded regret, even though the average cost grows without bound.

7.25. Perfect sampling for multiclass closed queueing networks

In [28] we present an exact sampling method for multiclass closed queuing networks. We consider networks for which stationary distribution does not necessarily have a product form. The proposed method uses a compact representation of sets of states, that is used to derive a bounding chain with significantly lower complexity of one-step transition in the coupling from the past scheme. The coupling time of this bounding chain can be larger than the coupling time of the exact chain, but it is finite in expectation. Numerical experiments show that coupling time is close to that of the exact chain. Moreover, the running time of the proposed algorithm outperforms the classical algorithm.

7.26. Fast and Memory Optimal Low-Rank Matrix Approximation

In this paper, we revisit the problem of constructing a near-optimal rank k approximation of a matrix $M \in [0,1]^{m \times n}$ under the streaming data model where the columns of M are revealed sequentially. We present SLA (Streaming Low-rank Approximation), an algorithm that is asymptotically accurate, when $ks_{k+1}(M) = o(\sqrt{mn})$ where $s_{k+1}(M)$ is the $(k+1)$-th largest singular value of M. This means that its average mean-square error converges to 0 as m and n grow large (i.e., $\|\widehat{M}^{(k)} - M^{(k)}\|_F^2 = o(mn)$ with high probability, where $\widehat{M}^{(k)}$ and $M^{(k)}$ denote the output of SLA and the optimal rank k approximation of M, respectively). Our algorithm makes one pass on the data if the columns of M are revealed in a random order, and two passes if the columns of M arrive in an arbitrary order. To reduce its memory footprint and complexity, SLA uses random sparsification, and samples each entry of M with a small probability δ. In turn, SLA is memory optimal as its required memory space scales as $k(m+n)$, the dimension of its output. Furthermore, SLA is computationally efficient as it runs in $O(\delta kmn)$ time (a constant number of operations is made for each observed entry of M), which can be as small as $O(k \log(m)^4 n)$ for an appropriate choice of δ and if $n \geq m$.

7.27. Combinatorial Bandits Revisited

[43] investigates stochastic and adversarial combinatorial multi-armed bandit problems. In the stochastic setting under semi-bandit feedback, we derive a problem-specific regret lower bound, and discuss its scaling with the dimension of the decision space. We propose ESCB, an algorithm that efficiently exploits the structure of the problem and provide a finite-time analysis of its regret. ESCB has better performance guarantees than existing algorithms, and significantly outperforms these algorithms in practice. In the adversarial setting under bandit feedback, we propose COMBEXP, an algorithm with the same regret scaling as state-of-the-art algorithms, but with lower computational complexity for some combinatorial problems.

7.28. Non-backtracking spectrum of random graphs: community detection and non-regular Ramanujan graphs

A non-backtracking walk on a graph is a directed path such that no edge is the inverse of its preceding edge. The non-backtracking matrix of a graph is indexed by its directed edges and can be used to count non-backtracking walks of a given length. It has been used recently in the context of community detection and has appeared previously in connection with the Ihara zeta function and in some generalizations of Ramanujan graphs. In [27], we study the largest eigenvalues of the non-backtracking matrix of the Erdos-Renyi random graph and of the Stochastic Block Model in the regime where the number of edges is proportional to the number of vertices. Our results confirm the "spectral redemption" conjecture that community detection can be made on the basis of the leading eigenvectors above the feasibility threshold.

7.29. Designing Adaptive Replication Schemes in Distributed Content Delivery Networks

In [33], we address the problem of content replication in large distributed content delivery networks, composed of a data center assisted by many small servers with limited capabilities and located at the edge of the network. The objective is to optimize the placement of contents on the servers to offload as much as possible the data center. We model the system constituted by the small servers as a loss network, each loss corresponding to a request to the data center. Based on large system / storage behavior, we obtain an asymptotic formula for the optimal replication of contents and propose adaptive schemes related to those encountered in cache networks but reacting here to loss events, and faster algorithms generating virtual events at higher rate while keeping the same target replication. We show through simulations that our adaptive schemes outperform significantly standard replication strategies both in terms of loss rates and adaptation speed.

7.30. Spectral Detection in the Censored Block Model

In [37], we consider the problem of partially recovering hidden binary variables from the observation of (few) censored edge weights, a problem with applications in community detection, correlation clustering and synchronization. We describe two spectral algorithms for this task based on the non-backtracking and the Bethe Hessian operators. These algorithms are shown to be asymptotically optimal for the partial recovery problem, in that they detect the hidden assignment as soon as it is information theoretically possible to do so.

7.31. A spectral method for community detection in moderately-sparse degree-corrected stochastic block models

In the ordinary stochastic block model, all degrees in a cluster have the same expected degree. The Degree-Corrected Stochastic Block Models (DC-SBM) is a generalization of the former where the expected degrees of individual nodes follow a prescribed degree-sequence. We consider community detection in the DC-SBM in a paper currently in preparation [44]. We perform spectral clustering on a suitably normalized adjacency matrix. This leads to consistent recovery of the block-membership of all but a vanishing fraction of nodes, in the regime where the lowest degree is of order $\log(n)$ or higher. The main contributions of this paper are (i) the fact that recovery succeeds for very heterogeneous degree-distributions and (ii) a clean analysis for the DC-SBM, which is a messy model.

7.32. An Impossibility Result for Reconstruction in a Degree-Corrected Planted-Partition Model

In a paper currently in preparation [45], we consider a degree-corrected planted-partition model: a random graph on n nodes with two equal-sized clusters. The model parameters are two constants $a, b > 0$ and an i.i.d. sequence $(\phi_i)_{i=1}^n$, with finite second moment Φ^2. Vertices i and j are joined by an edge with probability $\frac{\phi_i \phi_j}{n} a$ whenever they are in the same class and with probability $\frac{\phi_i \phi_j}{n} b$ otherwise. We prove that the underlying community structure cannot be accurately recovered from observations of the graph when $(a-b)^2 \Phi^2 \leq 2(a+b)$.

7.33. Universality in polytope phase transitions and message passing algorithms

In [5], we consider a class of nonlinear mappings $\mathsf{F}_{A,N}$ in $\mathbb{R}^N$ indexed by symmetric random matrices $A \in \mathbb{R}^{N\times N}$ with independent entries. Within spin glass theory, special cases of these mappings correspond to iterating the TAP equations and were studied by Bolthausen [Comm. Math. Phys. 325 (2014) 333-366]. Within information theory, they are known as "approximate message passing" algorithms. We study the high-dimensional (large N) behavior of the iterates of F for polynomial functions F, and prove that it is universal; that is, it depends only on the first two moments of the entries of A, under a sub-Gaussian tail condition. As an application, we prove the universality of a certain phase transition arising in polytope geometry and compressed sensing. This solves, for a broad class of random projections, a conjecture by David Donoho and Jared Tanner.

7.34. Contagions in Random Networks with Overlapping Communities

In [14], we consider a threshold epidemic model on a clustered random graph with overlapping communities. In other words, our epidemic model is such that an individual becomes infected as soon as the proportion of her infected neighbors exceeds the threshold q of the epidemic. In our random graph model, each individual can belong to several communities. The distributions for the community sizes and the number of communities an individual belongs to are arbitrary. We consider the case where the epidemic starts from a single individual, and we prove a phase transition (when the parameter q of the model varies) for the appearance of a cascade, i.e. when the epidemic can be propagated to an infinite part of the population. More precisely, we show that our epidemic is entirely described by a multi-type (and alternating) branching process, and then we apply Sevastyanov's theorem about the phase transition of multi-type Galton-Watson branching processes. In addition, we compute the entries of the matrix whose largest eigenvalue gives the phase transition.

7.35. The Diameter of Weighted Random Graphs.

In [3], we study the impact of random exponential edge weights on the distances in a random graph and, in particular, on its diameter. Our main result consists of a precise asymptotic expression for the maximal weight of the shortest weight paths between all vertices (the weighted diameter) of sparse random graphs, when the edge weights are i.i.d. exponential random variables.

8. Bilateral Contracts and Grants with Industry

8.1. CRE with Orange

One year CRE contract titled “Détermination de la distribution des conditions radio validée avec les données terrain pour les outils de dimensionnement” (Determining the distribution of the radio channel conditions validated by the real data for network dimensioning tools) between Inria and Orange Labs have been signed in 2015. It is a part of the long-term collaboration between TREC/DYOGENE and Orange Labs, represented by M. K. Karray, for the development of analytic tools for the QoS evaluation and dimensioning of operator cellular networks. Arpan Chattopadhyay was hired by Inria as a post-doctoral fellow thanks to this contract.

8.2. MSR-Inria Joint Lab

- Social Information Networks and Privacy
  Online Social networks provide a new way of accessing and collectively treating information. Their efficiency is critically predicated on the quality of information provided, the ability of users to assess such quality, and to connect to like-minded users to exchange useful content.

  To improve this efficiency, we develop mechanisms for assessing users' expertise and recommending suitable content. We further develop algorithms for identifying latent user communities and recommending potential contacts to users.

- Machine Learning and Big Data
  Multi-Armed Bandit (MAB) problems constitute a generic benchmark model for learning to make sequential decisions under uncertainty. They capture the trade-off between exploring decisions to learn the statistical properties of the corresponding rewards, and exploiting decisions that have generated the highest rewards so far. In this project, we aim at investigating bandit problems with a large set of available decisions, with structured rewards. The project addresses bandit problems with known and unknown structure, and targets specific applications in online advertising, recommendation and ranking systems.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. GdR GeoSto

Members of Dyogene participate in Research Group GeoSto (Groupement de recherche, GdR 3477) http://gdr-geostoch.math.cnrs.fr/ on Stochastic Geometry led by Pierre Calka [Université de Rouen]. This is a collaboration framework for all French research teams working in the domain of spatial stochastic modeling, both on theory development and in applications.

9.1.2. ANR

9.1.2.1. ANR GAP

Graphs, Algorithms and Probability - PI: Marc Lelarge; started in Jan 2012 - 48 months. http://www.di.ens.fr/~lelarge/ANR-GAP.html

Over the last few years, several research areas have witnessed important progress through the fruitful collaboration of mathematicians, theoretical physicists and computer scientists. One of them is the cavity method. Originating from the theory of mean field spin glasses, it is key to understanding the structure of Gibbs measures on diluted random graphs, which play a key role in many applications, ranging from statistical inference to optimization, coding and social sciences.

The objective of this project is to develop mathematical tools in order to contribute to a rigorous formalization of the cavity method:

- From local to global, the cavity method on diluted graphs. We will study the extent to which the global properties of a random process defined on some graph are determined by the local properties of interactions on this graph. To this end, we will relate the cavity method to the analysis of the complex zeros of the partition function, an approach that also comes from statistical mechanics. This will allow us to apply new techniques to the study of random processes on large diluted graphs and associated random matrices.
- Combinatorial optimization, network algorithms, statistical inference and social sciences. Motivated by combinatorial optimization problems, we will attack long-standing open questions in theoretical computer science with the new tools developed in the first project. We expect to design new distributed algorithms for communication networks and new algorithms for inference in graphical models. We will also analyze networks from an economic perspective by studying games on complex networks.

9.1.2.2. ANR MARMOTE

Markovian Modeling Tools and Environments - coordinator: Alain Jean-Marie (Inria Maestro); local coordinator (for partner Inria Paris-Rocquencourt): A. Bušić; Started: January 2013; Duration: 48 months; partners: Inria Paris-Rocquencourt (EPI DYOGENE), Inria Sophia Antipolis Méditerranée (EPI MAESTRO), Inria Grenoble Rhône-Alpes (EPI MESCAL), Université Versaillese-St Quentin, Telecom SudParis, Université Paris-Est Creteil, Université Pierre et Marie Curie.

The aim of the project is to realize a modeling environment dedicated to Markov models. One part will develop the Perfect Simulation techniques, which allow to sample from the stationary distribution of the process. A second one will develop parallelization techniques for Monte Carlo simulation. A third one will develop numerical computation techniques for a wide class of Markov models. All these developments will be integrated into a programming environment allowing the specification of models and their solution strategy. Several applications will be studied in various scientific disciplines: physics, biology, economics, network engineering.

9.2. International Initiatives

9.2.1. Inria Associate Teams not involved in an Inria International Labs

9.2.1.1. PARIS

Title: Probabilistic Algorithms for Renewable Integration in Smart Grid

International Partner (Institution - Laboratory - Researcher):

University of Florida (United States) - Department of Electrical and Computer Engineering - Sean Meyn

Start year: 2015

See also: http://www.di.ens.fr/~busic/PARIS/

The importance of statistical modeling and probabilistic controlechniques in the power systems area is now evident to practitioners in both the U.S. and Europe. Increased introduction of renewable generation has brought unforeseen volatility to the grid that require new techniques in distributed and probabilistic control. This Associate Team brings together the complementary skills in optimization, Markov modeling, simulation, and stochastic networks with aim to help solving some pressing open problems in this area. This collaboration also opens many exciting new scientific questions in the broad area of stochastic modeling and control.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

- Venkatachalam Anantharam [Professor, University of California, Jul 2015]
- Bruce Hajek [Professor, CSL, from Feb 2015 until Mar 2015]
- Holger Keeler [Post-Doctoral Fellow, Weierstrass Institute, Mar 2015]
- Armand Makowski [Professor, University of Maryland, Jul 2015]
- Peter Marbach [Professor, University of Toronto, from Jan until Jul 2015]
- Piotr Markowski [PhD Student, University of Wroclaw, Jun 2015]
- Sean Meyn [Professor, University of Florida, Feb 2015 and Jul 2015]

9.3.2. Visits to International Teams

9.3.2.1. Research stays abroad

Bartek Blaszczyszyn was visiting Mathematical Department of Wroclaw Universty for two weeks in April and October 2015 giving a series of lectures on stochastic geometry and modeling of communication networks.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

- Bartek Blaszczyszyn and Marc Lelarge co-organized Stochastic networks and stochastic geometry conference dedicated to François Baccelli on his 60th birthday; http://www.di.ens.fr/~blaszczy/FB60/
- M. Lelarge: Co-organizer, Cargèse fall school on random graphs, with Dieter Mitsche and Pawel Pralat
  http://math.unice.fr/~dmitsche/Fallschool/Fallschool.html
- M. Lelarge: Co-organizer, Workshop on Community Detection, with Laurent Massoulié
  http://www.msr-inria.fr/conferences-workshops/workshop-on-community-detection-at-institut-henri-poincare/

10.1.1.1. Chair of conference program committees

Ana Busic: Valuetools 2015 TPC co-chair. http://valuetools.org/2015/show/home

10.1.1.2. Member of the conference program committees

- Bartek Blaszczyszyn: WiOpt/SpaSWiN 2015
- Anne Bouillard was a member of the program commitee of WiOpt 2015 and Valuetools 2015.
- Ana Busic: ACM Sigmetrics, WiOpt, IEEE SmartGridComm.
- Marc Lelarge: WEIS, WiOpt, WAW.

10.1.2. Journal

10.1.2.1. Member of the editorial boards

- F. Baccelli serves on the editorial borads of: Bernoulli, JAP, AAP et Questa.
- M. Lelarge serves on the editorial borads of: IEEE's Transactions on Network Science and Engineering, Bernoulli Journal and Queueing Systems.

10.1.3. Invited talks

- F. Baccelli gave the following invited lectures: Keynote Lecture, *ISWCS'15*, Brussels, August 2015; Invited lecture at the *Huawei Vision Forum, Paris*, on stochastic geometry for wireless networks, March 2015; Invited lecture at the *EPFL Inria Joint Meeting, Lausanne*, on coverage in cellular networks, January 2015.
- Bartek Blaszczyszyn: WiOpt/SpaSWiN 2015, Simons workshop on Stochastic Geometry and Networks, University of Texas at Austin.
- A. Busic: keynote talk at CaFFEET (California France Forum on Energy Efficiency Technologies); http://caffeet.com/
- M. Lelarge: The International Symposium on Optimization (ISMP), Pittsburgh (Jul.); CAp2015 : Conférence sur l'APprentissage automatique, Lille (Jul.); Algotel, Beaunes (Jun.); DALI 2015 - Workshop on Learning Theory, Spain (Apr.); Assemblée Générale du GdR Information Signal Image viSion (ISIS), Lyon (Apr.); Combinatorial and algorithmic aspects of convexity, Paris (Jan.).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence : Anne Bouillard (Cours) et Ana Busic (TD) **Structures et algorithmes aléatoires** 80heqTD, L3, ENS, France.

Licence : Anne Bouillard (Cours) **Théorie de l'information et du codage** 36 heqTD, L3, ENS, France.

Licence : Anne Bouillard (Cours) **Algorithmique et programmation** 21 heqTD, L3, ENS, France.

Licence : Anne Bouillard (TD) **Systèmes digitaux** 9 heqTD, L3, ENS, France.

Master: Bartek Blaszczyszyn (with Laurent Massoulié), Graduate Course on point processes, stochastic geometry and random graphs (program "Master de Sciences et Technologies"), 45h, UPMC, Paris 6, France.

Master : Bartek Blaszczyszyn (with Laurent Decreusefond), Graduate Course on Spatial Stochastic Modeling of Wireless Networks (master program "Advanced Communication Networks"), 45h, l'X and Telecom ParisTech, Paris.

Master : Anne Bouillard (Cours + TD) **Fondements de la modélisation des réseaux** 18heqTD, M2, MPRI, France

Master: Ana Busic et Marc Lelarge (Cours) et Rémi Varloot (TD) Modèles et algorithmes de réseaux, 50heqTD, M1, ENS, Paris, France.

Master: Ana Busic, Simulation, 9hCours, M2 AMIS, UVSQ, France

Master: Marc Lelarge (Cours), Algorithms for Networked Information, 27heqTD, M2 ACN, Ecole polytechnique

Master: Marc Lelarge (TD), Networks: distributed control and emerging phenomena, 36 heqTD, M1, Ecole polytechnique.

10.2.2. Supervision

HdR : Marc Lelarge, Topics in random graphs, combinatorial optimization, and statistical inference[2], ENS, 23 février 2015.

PhD : Miodrag Jovanovic, Evaluation and optimization of the quality perceived by mobile users for new services in cellular networks, started in January 2012, defended in 2015 advisor B. Blaszczyszyn, co-advisor M.Karray; [1]

PhD in progress : Kumar Gaurav, Convex comparison of network architectures, started in October 2011, advisor B. Blaszczyszyn;

PhD in progress : Christelle Rovetta, Applications of perfect sampling to queuing networks and random generation of combinatorial objects, from December 2013, co-advised by Anne Bouillard and Ana Busic;

PhD in progress : Umar Hashmi, Decentralized control for renewable integration in smartgrids, from December 2015, advisors: A. Busic and M. Lelarge;

PhD in progress: Lennart Gulikers, Spectral clustering, depuis décembre 2014, encadrants: Marc Lelarge et Laurent Massoulié

PhD in progress : Rémi Varloot, Dynamique de Formation des Réseaux, depuis février 2015, encadrants: Marc Lelarge et Laurent Massoulié

PhD in progress: Alexandre Hollocou, Local community detection, depuis décembre 2015, encadrants: Thomas Bonald et Marc Lelarge

10.2.3. Juries

- A. Busic: Examiner for PhD: Pierre-Antoine BRAMERET (ENS Cachan) 2015.
- A. Busic: membre du jury de recrutement CR2 Inria Saclay - Île-de-France.
- A. Busic: membre de la Commission des Emplois Scientifiques du CRI Paris-Rocquencourt
- A. Busic: membre de la Commission de développement technologique (CDT) de Paris-Rocquencourt
- M. Lelarge: External Examiner for PhD: Jean Barbier (ENS) and Hang Zhou (ENS)

- M. Lelarge: Member of the hiring committee for “maître de conférence Probabilités (Université Lyon 1)”

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] M. JOVANOVIC. *Evaluation and optimization of the quality of service perceived by mobile users for new services in cellular networks*, Télécom ParisTech, September 2015, https://hal.archives-ouvertes.fr/tel-01238450

[2] M. LELARGE. *Topics in random graphs, combinatorial optimization, and statistical inference*, ENS Paris - Ecole Normale Supérieure de Paris, February 2015, Habilitation à diriger des recherches, https://hal.archives-ouvertes.fr/tel-01254928

Articles in International Peer-Reviewed Journals

[3] H. AMINI, M. LELARGE. *The diameter of weighted random graphs*, in "The Annals of Applied Probability", June 2015, vol. 25, n^o 3 [*DOI :* 10.1214/14-AAP1034], https://hal.archives-ouvertes.fr/hal-01254904

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[5] *Best Paper*
M. BAYATI, M. LELARGE, A. MONTANARI. *Universality in polytope phase transitions and message passing algorithms*, in "Annals of Applied Probability", April 2015, vol. 25, n^o 2, pp. 753-822 [*DOI :* 10.1214/14-AAP1010], https://hal.archives-ouvertes.fr/hal-01254901.

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