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Project-Team DYOGENE

Dynamics of Geometric Networks

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

RESEARCH CENTER
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THEME
Networks and Telecommunications

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Project-Team DYOGENE

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DYOGENE is also affiliated with Ecole normale supérieure de Paris, CNRS, Département d'Informatique de l'Ecole Normale Supérieure (UMR8548). It follows DYOGEN (team created in Feb 2013 and stopped at the creation of the current EPI).

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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 [64] is a theory for obtaining deterministic upper bounds in networks that has been developed by R. Cruz [53], [54]. 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 [66] have introduced a perfect sampling algorithm (PSA) that has later been extended and applied in various contexts, including statistical physics [58], stochastic geometry [62], theoretical computer science [51], and communications networks [49], [57] (see also the annotated bibliography by Wilson [71]).

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 a *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 [69] 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 [67]).

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 [68], signal processing [56] and social sciences [61]. 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 [52], 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. 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.

4.2. Routing protocols

Routing protocols enables to maintain paths for transmitting messages over a network. Those protocols, such as OSPF, are based on the transmission of periodic messages between neighbors. Nowadays, faulty behaviors result in the raising of alarms, but are mostly detected when a breakdown or a major misbehavior occurs. Indeed, alarms are so numerous that thay cannot be analyzed efficiently. We aim at developing methods to detect misbehaviours of a router befor a major fault accurs, and techniques to study the influence of the protocol parameters on the bahavior of the network.

4.3. 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.

4.4. Peer-to-Peer Systems

The amount of multimedia traffic accessed via the Internet, already of the order of exabytes (10^{18} bytes) per month, is expected to grow steadily in the coming years. A peer-to-peer (P2P) architecture, where peers contribute resources to support service of such traffic, holds the promise to support its growth more cheaply than by scaling up the size of data centers. More precisely, a large scale P2P system based on resources of individual users can absorb part of the load that would otherwise need to be served by data centers. In video-on-demand applications, the critical resources at the peers are storage space and uplink bandwidth. Our objective is to ensure that the largest fraction of traffic is supported by the P2P system.

4.5. Social and economic networks

Networks are ubiquitous with the presence of different kinds of social, economic and information networks around us. The Internet is one of the most prominent examples of a geometric network. We also examine geometric networks from the perspective of sociologist and economist [70]. Network analysis is also attracting foundational research by computer scientists [63]. Diffusion of information, social influence, trust, communication and cooperation between agents are heavily researched topics in e-commerce and multi-agent systems. Our probabilistic techniques are very appropriate in this case and have been largely neglected so far. While the first works on geometric networks emanated from theoretical physicists, they stay more focused on static properties of such networks and do not consider game theoretical or statistical learning (like community detection) aspects of such networks. This leaves open a range of new problems to which we will contribute.

5. Software and Platforms

5.1. SINR-based k-coverage probability in cellular networks

H. P. Keeler, "SINR-based k-coverage probability in cellular networks" MATLAB Central File Exchange, 2013.

Available at: http://www.mathworks.fr/matlabcentral/fileexchange/40087-sinr-based-k-coverage-probability-in-cellular-networks

The scripts calculate the SINR k-coverage probability in a single-tier cellular network using a method based on a homogeneous Poisson process model. Details can be found in [20] which presents the model that these scripts are based on.

6. New Results

6.1. Ancillary service to the grid from deferrable loads: the case for intelligent pool pumps in Florida

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. In [28], we focus on pool pumps, and how they can be used to provide ancillary service to the grid for maintaining demand-supply balance. A Markovian Decision Process (MDP) model is introduced for an individual pool pump. 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 pools is then developed by examining the mean field limit. A key innovation is an 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. Simulations are provided to illustrate the accuracy of the approximations and effectiveness of the proposed control approach.

6.2. Impact of Storage on the Efficiency and Prices in Real-Time Electricity Markets

In [19] we study the effect of energy-storage systems in dynamic real-time electricity markets. We consider that demand and renewable generation are stochastic, that real-time production is affected by ramping constraints, and that market players seek to selfishly maximize their profit. We distinguish three scenarios, depending on the owner of the storage system: (A) the supplier, (B) the consumer, or (C) a stand-alone player. In all cases, we show the existence of a competitive equilibrium when players are price-takers (they do not affect market prices). We further establish that under the equilibrium price process, players' selfish responses coincide with the social welfare-maximizing policy computed by a (hypothetical) social planner. We show that with storage the resulting price process is smoother than without. We determine empirically the storage parameters that maximize the players' revenue in the market. In the case of consumer-owned storage, or a stand-alone storage operator (scenarios B and C), we find that they do not match socially optimal parameters. We conclude that consumers and the stand-alone storage operator (but not suppliers) have an incentive to under-dimension their storage system. In addition, we determine the scaling laws of optimal storage parameters as a function of the volatility of demand and renewables. We show, in particular, that the optimal storage energy capacity scales as the volatility to the fourth power.

6.3. Risk-Aware SLA Negotiation

In order to assure Quality of Service (QoS) connectivity, Network Service Providers (NSPs) negotiate Service Level Agreements (SLAs). However, a committed SLA might fail to respect its QoS promises. In such a case, the customer is refunded. To maximize their revenues, the NSPs must deal with risks of SLA violations, which are correlated to their network capacities. Due to the complexity of the problem, we first study in [21], a system with one NSP provider and give a method to compute its risk-aware optimal strategy using (max; +)-algebras. Using the same method, we study the case where two NSPs collaborate and the case where they compete, and we derive the Price of Anarchy. This method provides optimal negotiation strategies but, when modeling customers' reaction to SLA failure, analytical results do not hold. Hence, we propose a learning framework that chooses the NSP risk-aware optimal strategy under failures capturing the impact of reputation. Finally, by simulation, we observe how the NSP can benefit from such a framework.

6.4. Impact of Rare Alarms on Event Correlation

Nowadays, telecommunication systems are growing more and more complex, generating a large amount of alarms that cannot be effectively managed by human operators. The problem is to detect significant combinations of alarms describing an issue in real-time. In [18], we present a powerful heuristic algorithm that constructs dependency graphs of alarm patterns. More precisely, it highlights patterns extracted from an alarm flow obtained from a learning process with a small footprint on network management system performance. This algorithm helps to detect issues in real-time by effectively delivering concise alarm patterns. Furthermore, it allows the proactive analysis of the functioning of a network by computing the general trends of this network. We evaluate our algorithm on an optical network alarm data set of an existing operator. We find similar results as the expert analysis performed for this operator by Alcatel-Lucent Customer Services.

6.5. Some Synchronization Issues in OSPF Routing

A routing protocol such as OSPF has a cyclic behavior to regularly update its view of the network topology. Its behavior is divided into periods. Each period produces a flood of network information messages. We observe a regular activity in terms of messages exchanges and filling of receive buffers in routers. [17] examines the consequences of possible overlap of activity between periods, leading to a buffer overflow. OSPF allows “out of sync" flows by considering an initial delay (phase). We study the optimum calculation of these offsets to reduce the load, while maintaining a short period to ensure a protocol reactive to topology changes. Such studies are conducted using a simulated Petri net model. A heuristic for determining initial delays is proposed. A core network in Germany serves as illustration.

6.6. Exact Worst-case Delay in FIFO-multiplexing Feed-forward Networks

In this paper 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.

6.7. Fast weak–KAM integrators for separable Hamiltonian systems

We consider a numerical scheme for Hamilton–Jacobi equations based on a direct discretization of the Lax–Oleinik semi–group. We prove that this method is convergent with respect to the time and space stepsizes provided the solution is Lipschitz, and give an error estimate. Moreover, we prove that the numerical scheme is a *geometric integrator* satisfying a discrete weak–KAM theorem which allows to control its long time behavior. Taking advantage of a fast algorithm for computing min–plus convolutions based on the decomposition of the function into concave and convex parts, we show that the numerical scheme can be implemented in a very efficient way.

6.8. Probabilistic cellular automata, invariant measures, and perfect sampling

A probabilistic cellular automaton (PCA) can be viewed as a Markov chain. The cells are updated synchronously and independently, according to a distribution depending on a finite neighborhood. In [9], we investigate the ergodicity of this Markov chain. A classical cellular automaton is a particular case of PCA. For a one-dimensional cellular automaton, we prove that ergodicity is equivalent to nilpotency, and is therefore undecidable. We then propose an efficient perfect sampling algorithm for the invariant measure of an ergodic PCA. Our algorithm does not assume any monotonicity property of the local rule. It is based on a bounding process which is shown to also be a PCA. Last, we focus on the PCA majority, whose asymptotic behavior is unknown, and perform numerical experiments using the perfect sampling procedure.

6.9. Density Classification on Infinite Lattices and Trees

Consider an infinite graph with nodes initially labeled by independent Bernoulli random variables of parameter p. In [7], we address the density classification problem, that is, we want to design a (probabilistic or deterministic)cellular automaton or a finite-range interacting particle system that evolves on this graph and decides whether p is smaller or larger than 1/2. Precisely, the trajectories should converge to the uniform configuration with only 0's if p<1/2, and only 1's if p>1/2. We present solutions to the problem on the regular grids of dimension d, for any d>1, and on the regular infinite trees. For the bi-infinite line, we propose some candidates that we back up with numerical simulations.

6.10. Semi-infinite paths of the radial spanning tree

In the paper [4], in collaboration with David Coupier and Viet Chi Tran of Lille 1, we study the semi-infinite paths of the radial spanning tree (RST) of a Poisson point process in the plane using Stochastic Geometry. We first show that the expectation of the number of intersection points between semi-infinite paths and the sphere with radius r grows sublinearly with r. Then, we prove that in each (deterministic) direction, there exists with probability one a unique semi-infinite path, framed by an infinite number of other semi-infinite paths of close asymptotic directions. The set of (random) directions in which there are more than one semi-infinite paths is dense in $[0, 2\pi)$. It corresponds to possible asymptotic directions of competition interfaces. We show that the RST can be decomposed in at most five infinite subtrees directly connected to the root. The interfaces separating these subtrees are studied and simulations are provided.

6.11. Generating functionals of random packing point processes

In the paper [45], we study the generating functionals of a class of random packing point processes of the Matérn type. Consider a symmetrical conflict relationship between the points of a point process. The Matérn type constructions provide a generic way of selecting a subset of this point process which is conflict-free. The simplest one consists in keeping only conflict-free points. There is however a wide class of Matérn type processes based on more elaborate selection rules and providing larger sets of selected points. The general idea being that if a point is discarded because of a given conflict, there is no need to discard other points with which it is also in conflict. The ultimate selection rule within this class is the so called Random Sequential Adsorption, where the cardinality of the sequence of conflicts allowing one to decide whether a given point is selected is *not* bounded. The present paper provides a sufficient condition on the span of the conflict relationship under which all the above point processes are well defined when the initial point process is Poisson. It then establishes, still in the Poisson case, a set of differential equations satisfied by the probability generating functionals of these Matérn type point processes. Integral equations are also given for the Palm distributions.

6.12. Clustering and percolation of point processes

We are interested in phase transitions in certain percolation models on point processes and their dependence on clustering properties of the point processes. In [5], we show that point processes with smaller void probabilities and factorial moment measures than the stationary Poisson point process exhibit non-trivial phase transition in the percolation of some coverage models based on level-sets of additive functionals of the point process. Examples of such point processes are determinantal point processes, some perturbed lattices, and more generally, negatively associated point processes. Examples of such coverage models are k-coverage in the Boolean model (coverage by at least k grains) and SINR-coverage (coverage if the signal-to-interference-and-noise ratio is large). In particular, we answer in affirmative the hypothesis of existence of phase transition in the percolation of k-faces in the Čech simplicial complex (also called clique percolation) on point processes which cluster less than the Poisson process. We also construct a Cox point process, which is “more clustered" than the Poisson point process and whose Boolean model percolates for arbitrarily small radius. This shows that clustering (at least, as detected by our specific tools) does not always “worsen” percolation, as well as that upper-bounding this clustering by a Poisson process is a necessary assumption for the phase transition to hold.

6.13. Using Poisson processes to model lattice cellular networks

An almost ubiquitous assumption made in the stochastic-analytic approach to study of the quality of user-service in cellular networks is Poisson distribution of base stations, often completed by some specific assumption regarding the distribution of the fading (e.g. Rayleigh). The former (Poisson) assumption is usually (vaguely) justified in the context of cellular networks, by various irregularities in the real placement of base stations, which ideally should form a lattice (e.g. hexagonal) pattern. In the first part of [14] we provide a different and rigorous argument justifying the Poisson assumption under sufficiently strong log-normal shadowing observed in the network, in the evaluation of a natural class of the typical-user service-characteristics (including path-loss, interference, signal-to-interference ratio, spectral efficiency). Namely, we present a Poisson-convergence result for a broad range of stationary (including lattice) networks subject to log-normal shadowing of increasing variance. We show also for the Poisson model that the distribution of all these typical-user service characteristics does not depend on the particular form of the additional fading distribution. Our approach involves a mapping of 2D network model to 1D image of it “perceived” by the typical user. For this image we prove our Poisson convergence result and the invariance of the Poisson limit with respect to the distribution of the additional shadowing or fading. Moreover, in the second part of the paper we present some new results for Poisson model allowing one to calculate the distribution function of the SINR in its whole domain. We use them to study and optimize the mean energy efficiency in cellular networks.

6.14. Compactification of the Action of a Point-Shift on the Palm Probability of a Point Process

In collaboration with Mir-Omid Haji-Mirsadeghi (Sharif University, Iran) [50], we analyzed the compactification of Palm probabilities by the action of a point–shift. A point-shift maps, in a translation invariant way, each point of a stationary point process Φ to some point of Φ. The initial motivation of this paper is the construction of probability measures, defined on the space of counting measures with an atom at the origin, which are left invariant by a given point-shift f. The point-shift probabilities of Φ are defined from the action of the semigroup of point-shift translations on the space of Palm probabilities, and more precisely from the compactification of the orbits of this semigroup action. If the point-shift probability is uniquely defined, and if f is continuous with respect to the vague topology, then the point-shift probability of Φ provides a solution to the initial question. Point-shift probabilities are shown to be a strict generalization of Palm probabilities: when the considered point-shift f is bijective, the point-shift probability of Φ boils down to the Palm probability of Φ. When it is not bijective, there exist cases where the point-shift probability of Φ is the law of Φ under the Palm probability of some stationary thinning Ψ of Φ. But there also exist cases where the point-shift probability of Φ is singular w.r.t. the Palm probability of Φ and where, in addition, it cannot be the law of Φ under the Palm probability of any stationary point process Ψ jointly stationary with Φ. The paper also gives a criterium of existence of the point-shift probabilities of a stationary point process and discusses uniqueness. The results are illustrated through several examples.

6.15. A Stochastic Geometry Framework for Analyzing Pairwise-Cooperative Cellular Networks

Cooperation in cellular networks has been recently suggested as a promising scheme to improve system performance, especially for cell-edge users. In [34], we use stochastic geometry to analyze cooperation models where the positions of Base Stations (BSs) follow a Poisson point process distribution and where Voronoi cells define the planar areas associated with them. For the service of each user, either one or two BSs are involved. If two, these cooperate by exchange of user data and channel related information with conferencing over some backhaul link. Our framework generally allows variable levels of channel information at the transmitters. In this paper we investigate the case of limited channel state information for cooperation (channel phase, second neighbour interference), but not the fully adaptive case which would require considerable feedback. The total per-user transmission power is further split between the two transmitters and a common message is encoded. The decision for a user to choose service with or without cooperation is directed by a family of geometric policies depending on its relative position to its two closest base stations. An exact expression of the network coverage probability is derived. Numerical evaluation allows one to analyze significant coverage benefits compared to the non-cooperative case. As a conclusion, cooperation schemes can improve system performance without exploitation of extra network resources.

6.16. SINR-based k-coverage probability in cellular networks with arbitrary shadowing

In [20], we give numerically tractable, explicit integral expressions for the distribution of the signal-to-interference-and-noise-ratio (SINR) experienced by a typical user in the down-link channel from the k-th strongest base stations of a cellular network modelled by Poisson point process on the plane. Our signal propagation-loss model comprises of a power-law path-loss function with arbitrarily distributed shadowing, independent across all base stations, with and without Rayleigh fading. Our results are valid in the whole domain of SINR, in particular for $SINR < 1$, where one observes multiple coverage. In this latter aspect our paper complements previous studies reported in [55].

6.17. Equivalence and comparison of heterogeneous cellular networks

In [15], we consider a general heterogeneous network in which, besides general propagation effects (shadowing and/or fading), individual base stations can have different emitting powers and be subject to different parameters of Hata-like path-loss models (path-loss exponent and constant) due to, for example, varying antenna heights. We assume also that the stations may have varying parameters of, for example, the link layer performance (SINR threshold, etc). By studying the *propagation processes* of signals received by the typical user from all antennas marked by the corresponding antenna parameters, we show that seemingly different heterogeneous networks based on Poisson point processes can be equivalent from the point of view a typical user. These neworks can be replaced with a model where all the previously varying propagation parameters (including path-loss exponents) are set to constants while the only trade-off being the introduction of an isotropic base station density. This allows one to perform analytic comparisons of different network models via their isotropic representations. In the case of a constant path-loss exponent, the isotropic representation simplifies to a homogeneous modification of the constant intensity of the original network, thus generalizing a previous result showing that the propagation processes only depend on one moment of the emitted power and propagation effects. We give examples and applications to motivate these results and highlight an interesting observation regarding random path-loss exponents.

6.18. How user throughput depends on the traffic demand in large cellular networks: a typical cell analysis and real network measurements

In [40], we assume a space-time Poisson process of call arrivals on the infinite plane, independently marked by data volumes and served by a cellular network modeled by an infinite ergodic point process of base stations. Each point of this point process represents the location of a base station that applies a processor sharing policy to serve users arriving in its vicinity, modeled by the Voronoi cell, possibly perturbed by some random signal propagation effects. User service rates depend on their signal-to-interference-and-noise ratios with respect to the serving station. Little's that allows to express the mean user throughput in any region of this network model as the ratio of the mean traffic demand to the steady-state mean number of users in this region. Using ergodic arguments and the Palm theoretic formalism, we define a global mean user throughput in the cellular network and prove that it is equal to the ratio of mean traffic demand to the mean number of users in the steady state of the "typical cell" of the network. Here, both means account for double averaging: over time and network geometry, and can be related to the per-surface traffic demand, base-station density and the spatial distribution of the signal-to-interference-and-noise ratio. This latter accounts for network irregularities, shadowing and cell dependence via some cell-load equations. Inspired by the analysis of the typical cell, we propose also a simpler, approximate, but fully analytic approach, called the mean cell approach. The key quantity explicitly calculated in this approach is the cell load. In analogy to the load factor of the (classical) M/G/1 processor sharing queue, it characterizes the stability condition, mean number of users and the mean user throughput. We validate our approach comparing analytical and simulation results for Poisson network model to real-network measurements.

6.19. Analysis of a Proportionally Fair and Locally Adaptive spatial Aloha in Poisson Networks

The proportionally fair sharing of the capacity of a Poisson network using Spatial-Aloha leads to closed-form performance expressions in two extreme cases: (1) the case without topology information, where the analysis boils down to a parametric optimization problem leveraging stochastic geometry; (2) the case with full network topology information, which was recently solved using shot-noise techniques. In [37], we show that there exists a continuum of adaptive controls between these two extremes, based on local stopping sets, which can also be analyzed in closed form. We also show that these control schemes are implementable, in contrast to the full information case which is not. As local information increases, the performance levels of these schemes are shown to get arbitrarily close to those of the full information scheme. The analytical results are combined with discrete event simulation to provide a detailed evaluation of the performance of this class of medium access controls.

6.20. Optimal Rate sampling in 802.11 Systems

In 802.11 systems, Rate Adaptation (RA) is a fundamental mechanism allowing transmitters to adapt the coding and modulation scheme as well as the MIMO transmission mode to the radio channel conditions, and in turn, to learn and track the (mode, rate) pair providing the highest throughput. So far, the design of RA mechanisms has been mainly driven by heuristics. In contrast, in [42], we rigorously formulate such design as an online stochastic optimisation problem. We solve this problem and present ORS (Optimal Rate Sampling), a family of (mode, rate) pair adaptation algorithms that provably learn as fast as it is possible the best pair for transmission. We study the performance of ORS algorithms in both stationary radio environments where the successful packet transmission probabilities at the various (mode, rate) pairs do not vary over time, and in non-stationary environments where these probabilities evolve. We show that under ORS algorithms, the throughput loss due to the need to explore sub-optimal (mode, rate) pairs does not depend on the number of available pairs, which is a crucial advantage as evolving 802.11 standards offer an increasingly large number of (mode, rate) pairs. We illustrate the efficiency of ORS algorithms (compared to the state-of-the-art algorithms) using simulations and traces extracted from 802.11 test-beds.

6.21. Flooding in Weighted Sparse Random Graphs

In [3], we study the impact of edge weights on distances in sparse random graphs. We interpret these weights as delays and take them as independent and identically distributed exponential random variables. We analyze the weighted flooding time defined as the minimum time needed to reach all nodes from one uniformly chosen node and the weighted diameter corresponding to the largest distance between any pair of vertices. Under some standard regularity conditions on the degree sequence of the random graph, we show that these quantities grow as the logarithm of n when the size of the graph n tends to infinity. We also derive the exact value for the prefactor. These results allow us to analyze an asynchronous randomized broadcast algorithm for random regular graphs. Our results show that the asynchronous version of the algorithm performs better than its synchronized version: in the large size limit of the graph, it will reach the whole network faster even if the local dynamics are similar on average.

6.22. Viral Marketing On Configuration Model

In [38], we consider propagation of influence on a Configuration Model, where each vertex can be influenced by any of its neighbours but in its turn, it can only influence a random subset of its neighbours. Our (enhanced) model is described by the total degree of the typical vertex, representing the total number of its neighbours and the transmitter degree, representing the number of neighbours it is able to influence. We give a condition involving the joint distribution of these two degrees, which if satisfied would allow with high probability the influence to reach a non-negligible fraction of the vertices, called a *big (influenced) component*, provided that the source vertex is chosen from a set of *good pioneers*. We show that asymptotically the big component is essentially the same, regardless of the good pioneer we choose, and we explicitly evaluate the asymptotic relative size of this component. Finally, under some additional technical assumption we calculate the relative size of the set of good pioneers. The main technical tool employed is the “fluid limit” analysis of the joint exploration of the configuration model and the propagation of the influence up to the time when a big influenced component is completed. This method was introduced in [59] to study the giant component of the configuration model. Using this approach we study also a reverse dynamic, which traces all the possible sources of influence of a given vertex, and which by a new “duality” relation allows to characterise the set of good pioneers.

6.23. Pioneers of Influence Propagation in Social Networks

With the growing importance of corporate viral marketing campaigns on online social networks, the interest in studies of influence propagation through networks is higher than ever. In a viral marketing campaign, a firm initially targets a small set of pioneers and hopes that they would influence a sizeable fraction of the population by diffusion of influence through the network. In general, any marketing campaign might fail to go viral in the first try. As such, it would be useful to have some guide to evaluate the effectiveness of the campaign and judge whether it is worthy of further resources, and in case the campaign has potential, how to hit upon a good pioneer who can make the campaign go viral.

In [43], we present a diffusion model developed by enriching the generalized random graph (a.k.a. configuration model) to provide insight into these questions. We offer the intuition behind the results on this model, rigorously proved in [38], and illustrate them here by taking examples of random networks having prototypical degree distributions — Poisson degree distribution, which is commonly used as a kind of benchmark, and Power Law degree distribution, which is normally used to approximate the real-world networks. On these networks, the members are assumed to have varying attitudes towards propagating the information. We analyze three cases, in particular — (1) Bernoulli transmissions, when a member influences each of its friend with probability p; (2) Node percolation, when a member influences all its friends with probability p and none with probability $1 - p$; (3) Coupon-collector transmissions, when a member randomly selects one of his friends K times with replacement.

We assume that the configuration model is the closest approximation of a large online social network, when the information available about the network is very limited. The key insight offered by this study from a firm's perspective is regarding how to evaluate the effectiveness of a marketing campaign and do cost-benefit analysis by collecting relevant statistical data from the pioneers it selects. The campaign evaluation criterion is informed by the observation that if the parameters of the underlying network and the campaign effectiveness are such that the campaign can indeed reach a significant fraction of the population, then the set of good pioneers also forms a significant fraction of the population. Therefore, in such a case, the firms can even adopt the naïve strategy of repeatedly picking and targeting some number of pioneers at random from the population. With this strategy, the probability of them picking a good pioneer will increase geometrically fast with the number of tries.

6.24. Peer-to-Peer Networks

In [12], in collaboration with I. Norros (VTT, Finland) and F. Mathieu (Bell Labs), we propose a new model for peer-to-peer networking which takes the network bottlenecks into account beyond the access. This model can cope with key features of P2P networking like degree or locality constraints together with the fact that distant peers often have a smaller rate than nearby peers. Using a network model based on rate functions, we give a closed form expression of peers download performance in the system's fluid limit, as well as approximations for the other cases. Our results show the existence of realistic settings for which the average download time is a decreasing function of the load, a phenomenon that we call super-scalability.

6.25. Stability of the bipartite matching model

In [8], we consider the bipartite matching model of customers and servers introduced by Caldentey, Kaplan and Weiss (2009). Customers and servers play symmetrical roles. There are finite sets C and S of customer and server classes, respectively. Time is discrete and at each time step one customer and one server arrive in the system according to a joint probability measure μ on C× S, independently of the past. Also, at each time step, pairs of matched customers and servers, if they exist, depart from the system. Authorized em matchings are given by a fixed bipartite graph (C, S, E⊂ C × S). A matching policy is chosen, which decides how to match when there are several possibilities. Customers/servers that cannot be matched are stored in a buffer. The evolution of the model can be described by a discrete-time Markov chain. We study its stability under various admissible matching policies, including ML (match the longest), MS (match the shortest), FIFO (match the oldest), RANDOM (match uniformly), and PRIORITY. There exist natural necessary conditions for stability (independent of the matching policy) defining the maximal possible stability region. For some bipartite graphs, we prove that the stability region is indeed maximal for any admissible matching policy. For the ML policy, we prove that the stability region is maximal for any bipartite graph. For the MS and PRIORITY policies, we exhibit a bipartite graph with a non-maximal stability region.

6.26. Matchings on infinite graphs

Elek and Lippner (Proc. Am. Math. Soc. 138(8), 2939–2947, 2010) showed that the convergence of a sequence of bounded-degree graphs implies the existence of a limit for the proportion of vertices covered by a maximum matching. In [6], we provide a characterization of the limiting parameter via a local recursion defined directly on the limit of the graph sequence. Interestingly, the recursion may admit multiple solutions, implying non-trivial long-range dependencies between the covered vertices. We overcome this lack of correlation decay by introducing a perturbative parameter (temperature), which we let progressively go to zero. This allows us to uniquely identify the correct solution. In the important case where the graph limit is a unimodular Galton–Watson tree, the recursion simplifies into a distributional equation that can be solved explicitly, leading to a new asymptotic formula that considerably extends the well-known one by Karp and Sipser for Erdős-Rényi random graphs.

6.27. Double-hashing thresholds via local weak convergence.

A lot of interest has recently arisen in the analysis of multiple-choice "cuckoo hashing" schemes. In this context, a main performance criterion is the load threshold under which the hashing scheme is able to build a valid hashtable with high probability in the limit of large systems; various techniques have successfully been used to answer this question (differential equations, combinatorics, cavity method) for increasing levels of generality of the model. However, the hashing scheme analysed so far is quite utopic in that it requires to generate a lot of independent, fully random choices. Schemes with reduced randomness exists, such as "double hashing", which is expected to provide similar asymptotic results as the ideal scheme, yet they have been more resistant to analysis so far. In [22], we point out that the approach via the cavity method extends quite naturally to the analysis of double hashing and allows to compute the corresponding threshold. The path followed is to show that the graph induced by the double hashing scheme has the same local weak limit as the one obtained with full randomness.

6.28. Convergence of multivariate belief propagation, with applications to cuckoo hashing and load balancing

[23] is motivated by two applications, namely generalizations of cuckoo hashing, a computationally simple approach to assigning keys to objects, and load balancing in content distribution networks, where one is interested in determining the impact of content replication on performance. These two problems admit a common abstraction: in both scenarios, performance is characterized by the maximum weight of a generalization of a matching in a bipartite graph, featuring node and edge capacities. Our main result is a law of large numbers characterizing the asymptotic maximum weight matching in the limit of large bipartite random graphs, when the graphs admit a local weak limit that is a tree. This result specializes to the two application scenarios, yielding new results in both contexts. In contrast with previous results, the key novelty is the ability to handle edge capacities with arbitrary integer values. An analysis of belief propagation algorithms (BP) with multivariate belief vectors underlies the proof. In particular, we show convergence of the corresponding BP by exploiting monotonicity of the belief vectors with respect to the so-called upshifted likelihood ratio stochastic order. This auxiliary result can be of independent interest, providing a new set of structural conditions which ensure convergence of BP.

6.29. Bypassing correlation decay for matchings with an application to XORSAT

Many combinatorial optimization problems on sparse graphs do not exhibit the correlation decay property. In such cases, the cavity method remains a sophisticated heuristic with no rigorous proof. In [24], we consider the maximum matching problem which is one of the simplest such example. We show that monotonicity properties of the problem allows us to define solutions for the cavity equations. More importantly, we are able to identify the 'right' solution of these equations and then to compute the asymptotics for the size of a maximum matching. The results for finite graphs are self-contained. We give references to recent extensions making use of the notion of local weak convergence for graphs and the theory of unimodular networks.

As an application, we consider the random XORSAT problem which according to the physics literature has a 'one-step replica symmetry breaking' (1RSB) glass phase. We derive new bounds on the satisfiability threshold valid for general graphs (and conjectured to be tight).

6.30. Sublinear-Time Algorithms for Monomer-Dimer Systems on Bounded Degree Graphs

For a graph G, let $Z(G, \lambda)$ be the partition function of the monomer-dimer system defined by $\sum_k m_k(G)\lambda^k$, where $m_k(G)$ is the number of matchings of size k in G. In [27], we consider graphs of bounded degree and develop a sublinear-time algorithm for estimating $\log Z(G, \lambda)$ at an arbitrary value $\lambda > 0$ within additive error ϵn with high probability. The query complexity of our algorithm does not depend on the size of G and is polynomial in $1/\epsilon$, and we also provide a lower bound quadratic in $1/\epsilon$ for this problem. This is the first analysis of a sublinear-time approximation algorithm for a $\#P$-complete problem. Our approach is based on the correlation decay of the Gibbs distribution associated with $Z(G, \lambda)$. We show that our algorithm approximates the probability for a vertex to be covered by a matching, sampled according to this Gibbs distribution, in a near-optimal sublinear time. We extend our results to approximate the average size and the entropy of such a matching within an additive error with high probability, where again the query complexity is polynomial in $1/\epsilon$ and the lower bound is quadratic in $1/\epsilon$. Our algorithms are simple to implement and of practical use when dealing with massive datasets. Our results extend to other systems where the correlation decay is known to hold as for the independent set problem up to the critical activity.

6.31. Reconstruction in the Labeled Stochastic Block Model

The labeled stochastic block model is a random graph model representing networks with community structure and interactions of multiple types. In its simplest form, it consists of two communities of approximately equal size, and the edges are drawn and labeled at random with probability depending on whether their two endpoints belong to the same community or not.

It has been conjectured that this model exhibits a phase transition: reconstruction (i.e. identification of a partition positively correlated with the true partition into the underlying communities) would be feasible if and only if a model parameter exceeds a threshold.

In [25], we prove one half of this conjecture, i.e., reconstruction is impossible when below the threshold. In the converse direction, we introduce a suitably weighted graph. We show that when above the threshold by a specific constant, reconstruction is achieved by (1) minimum bisection, and (2) a spectral method combined with removal of nodes of high degree.

6.32. Spectrum Bandit Optimisation

In [26], we consider the problem of allocating radio channels to links in a wireless network. Links interact through interference, modelled as a conflict graph (i.e., two interfering links cannot be simultaneously active on the same channel). We aim at identifying the channel allocation maximizing the total network throughput over a finite time horizon. Should we know the average radio conditions on each channel and on each link, an optimal allocation would be obtained by solving an Integer Linear Program (ILP). When radio conditions are unknown a priori, we look for a sequential channel allocation policy that converges to the optimal allocation while minimizing on the way the throughput loss or *regret* due to the need for exploring sub-optimal allocations. We formulate this problem as a generic linear bandit problem, and analyze it first in a stochastic setting where radio conditions are driven by a stationary stochastic process, and then in an adversarial setting where radio conditions can evolve arbitrarily. We provide, in both settings, algorithms whose regret upper bounds outperform those of existing algorithms for linear bandit problems.

6.33. Randomized Consensus with Attractive and Repulsive Links

In [29], we study convergence properties of a randomized consensus algorithm over a graph with both attractive and repulsive links. At each time instant, a node is randomly selected to interact with a random neighbor. Depending on if the link between the two nodes belongs to a given subgraph of attractive or repulsive links, the node update follows a standard attractive weighted average or a repulsive weighted average, respectively. The repulsive update has the opposite sign of the standard consensus update. In this way, it counteracts the consensus formation and can be seen as a model of link faults or malicious attacks in a communication network, or the impact of trust and antagonism in a social network. Various probabilistic convergence and divergence conditions are established. A threshold condition for the strength of the repulsive action is given for convergence in expectation: when the repulsive weight crosses this threshold value, the algorithm transits from convergence to divergence. An explicit value of the threshold is derived for classes of attractive and repulsive graphs. The results show that a single repulsive link can sometimes drastically change the behavior of the consensus algorithm. They also explicitly show how the robustness of the consensus algorithm depends on the size and other properties of the graphs.

6.34. Continuous-time Distributed Optimization of Homogenous Dynamics

This paper explores the fundamental properties of distributed minimization of a sum of functions with each function only known to one node, and a pre-specified level of node knowledge and computational capacity. We define the optimization information each node receives from its objective function, the neighboring information each node receives from its neighbors, and the computational capacity each node can take advantage of in controlling its state. It is proven that there exist a neighboring information way and a control law that guarantee global optimal consensus if and only if the solution sets of the local objective functions admit a nonempty intersection set for fixed strongly connected graphs. Then we show that for any tolerated error, we can find a control law that guarantees global optimal consensus within this error for fixed, bidirectional, and connected graphs under mild conditions. For time-varying graphs, we show that optimal consensus can always be achieved as long as the graph is uniformly jointly strongly connected and the nonempty intersection condition holds. The results illustrate that nonempty intersection for the local optimal solution sets is a critical condition for successful distributed optimization for a large class of algorithms.

6.35. Two-target Algorithms for Infinite-Armed Bandits with Bernoulli Rewards

In [16], we consider an infinite-armed bandit problem with Bernoulli rewards. The mean rewards are independent, uniformly distributed over $[0,1]$. Rewards 0 and 1 are referred to as a success and a failure, respectively. We propose a novel algorithm where the decision to exploit any arm is based on two successive targets, namely, the total number of successes until the first failure and until the first m failures, respectively, where m is a fixed parameter. This two-target algorithm achieves a long-term average regret in $\sqrt{2n}$ for a large parameter m and a known time horizon n. This regret is optimal and strictly less than the regret achieved by the best known algorithms, which is in $2\sqrt{n}$. The results are extended to any mean-reward distribution whose support contains 1 and to unknown time horizons. Numerical experiments show the performance of the algorithm for finite time horizons.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. CRE Inria-Orange

"Distribution of the SINR in real networks" participants: B Błaszczyszyn, M. K. Karray (Orange Labs) and H.P. Keeler (hired by Inria as a research engineer) started 01/11/2013, ends 01/11/2014

7.2. Bilateral Grants with Industry

7.2.1. Alcatel Lucent

The collaboration with Alcatel Lucent (France) went on with the postdoctoral position of Chandramani Singh, funded by the Alcatel–Lucent/Inria joint lab. This materilized into two publications on the game theoretic analysis of Spatial Aloha, including one paper to appear in the Proceedings of Infocom'14.

7.2.2. Qualcom

The collaboration with Qualcomm (USA) led to a new line of research on the analysis of MAC protocols in Vehicular Networks. This materilized into a publications on the analysis of CSMA in dense Vehicular Networks that appeared in the Proceedings of IEEE Infocom'13, and in the hiring of Tien Viet Nguyen in the team of T. Richardson at Qualcomm NJ.

7.2.3. CIFRE Orange

PhD: Miodrag Jovanović
supervisorss: Bartek Błaszczyszyn, M.K. Karray

7.2.4. CIFRE Technicolor

PhD: Mathieu Leconte
supervisors: Marc Lelarge, Laurent Massoulié
title: Load-balancing and resource-provisioning in large distributed systems

8. Partnerships and Cooperations

8.1. Regional Initiatives

DYOGENE participates in the Laboratory of Information, Networking and Communication Sciences (LINCS) http://www.lincs.fr/ created on October 28th, 2010, by three French institutions of higher education and research: Inria, Institut Télécom and UPMC. Alcatel-Lucent joined the LINCS in February 2011 as a strategic partner.

8.2. National Initiatives

8.2.1. 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.

8.2.2. ANR

8.2.2.1. 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.

8.2.2.2. ANR MARMOTE

Markovian Modeling Tools and Environments - coordinator: Alain Jean-Marie (Inria Maestro); local coordinator (partner Inria Paris-Rocquencourt): A. Bušić; 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.

8.2.2.3. ANR MAGNUM

A. Bušić is a participant (within partner LIP6) of the national project ANR MAGNUM (Methodes Algorithmiques pour la Generation aleatoire Non Uniforme: Modeles et applications) (2010–2014), partners: LIP6, LIAFA, IGM. http://www-apr.lip6.fr/anrMagnum/.

8.3. International Initiatives

8.3.1. Inria Associate Teams

The third and last year of the Associate Team "IT-SG-WN" with the EECS department of UC Berkeley in the USA, funded from 2011 to 2014, was completed by a one month visit of Prof. Anantharam in Paris in June 2013 and a visit of F. Baccelli in Berkeley in November 2013. This Associate Team participated in the Inria@SiliconValley initiative. It led to several joint publications on Information Theory: http://www.di.ens.fr/~baccelli/IT_SG_WN_web_site.htm

8.3.2. Microsoft Research-Inria Joint Centre

DYOGENE is involved in two projetcs.

- Structured Large-Scale Machine Learning

Project summary: Machine learning is now ubiquitous in industry, science, engineering, and personal life. While early successes were obtained by applying off-the-shelf techniques, there are two main challeges faced by machine learning in the « big data » era : structure and scale. The project proposes to explore three axes, from theoretical, algorithmic and practical perspectives: (1) large-scale convex optimization, (2) large-scale combinatorial optimization and (3) sequential decision making for structured data. The project involves two Inria sites and four MSR sites.
As part of this project Florian Bourse (student at ENS) did an internship supervised by Marc Lelarge and Milan Vojnovic. Marc Lelarge visited MSR Cambridge and Milan Vojnovic visited Inria.

- Social information networks
  Project summary: 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.
  As part of this project Rui Wu (student at UIUC) did an internship supervised by Marc Lelarge and Laurent Massoulié.

8.3.3. Participation In other International Programs

Anne Bouillard is participating in the joint lab Inria-Alcatel-Lucent and collaborated with B. Ronot [18].

Anne Bouillard is collaborating with Giovanni Stea from the University of Pisa, Italy.

Marc Lelarge is part of the IFCAM project: Application of optimal control and game theory in communication networks (PIs: Rajesh Sundaresan (Indian Institute of Science) and Eitan Altman (Inria))

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Vijay Subramanian (Northwestern University), April 8-12, 2013.
- Venkatachalam Anantharam (UC Berkeley), June 2013.
- Moez Draief (Imperial College London), July 2013.
- Hermann Thorisson (University of Iceland), September-October 2013.
- Sean Meyn (University of Florida), November 24-30, 2013.
- Rajesh Sundaresan (Indian Institute of Science), December 1-5, 2013.

8.4.1.1. Internships

- Asma Ghorbel (EURECOM), August 2013 to January 2014; Subject: *LTE/LTE-A Network Optimization by Distributed Fast Algorithms*; co-advised with Chung Shue (Calvin) Chen (Alcatel-Lucent Bell Labs).
- Rémi Varloot (ENS), MPRI internship, March-August 2013; Subject: *Coupling From the Past with Oracle Skipping*.
- Rui Wu (UIUC), September-December 2013.
- Jiaming Xu (UIUC), September 16-20, 2013.

8.4.2. Visits to International Teams

Anne Bouillard was invited at Tokyo institute of Technology, Japan from March to September 2013.

B. Błaszczyszyn visited Probability and Stochastic Processes team at the University of Wroclaw.

9. Dissemination

9.1. Scientific Animation

- François Baccelli:
  - Member of IFIP WG 7.3,
  - Advisory Editor, Queueing Systems, Springer Verlag,
  - Associate Editor IEEE Tr Information Theory,
  - TPC Member IEEE Wiopt 2013,
  - TPC Member IEEE ISIT 2013.
  - Organization of the first Simons Lectures on Network Mathematics in May 2013: http://www.ma.utexas.edu/conferences/SimonsChairLectures/
  - Co-organization of the workshop "Modern probabilistic techniques for design, stability, large deviations, and performance analysis of communication, social, energy, and other stochastic systems and networks", Isaac Newton Institute, Cambridge, UK, 12-16 August 2013.
  - Inaugural lecture at the Workshop on Geometry and Physics of Spatial Random Systems, Aarhus, Denmark, April 2013, on stochastic geometry and information theory.
  - Invited lecture at the Asymptotics of Large-Scale Interacting Networks Workshop, Banff, February-March 2013, on the dynamics of peer to peer networks.
- Bartek Błaszczyszyn:
  - reviewer of all major IEEE journals publishing in wireless domain,
  - organizing and co-chairing of the "Workshop on Spatial Stochastic Models for Wireless Networks" in Riva del Garda, Italy (2005), Berlin, Germany (2008), Tokyo, Japan (2013).
  - organizing and chairing of the 17th Workshop on Stochastic Geometry, Stereology and Image Analysis, Torun, Poland 2013.
  - Reviewer for DIGITEO and Israel Science Foundation.
- Ana Bušić:
  - TPC Member Performance 2013; http://performance.cs.univie.ac.at/.
  - TPC Member Valuetools 2013; http://valuetools.org/2013/show/home.
- Marc Lelarge:
  - Associate Editor: QUESTA, Bernoulli
  - TPC Member IEEE Wiopt 2013
  - TPC Member ACM SIGMETRICS 2013,
  - Reviewer for Swiss National Science Foundation.
- Alexandre Proutière:
  - Associate editor of IEEE transactions on Networking, Queueing Systems.
  - TPC: ACM Mobihoc, IEEE Infocom, Performance.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence : Anne Bouillard, Strucures et algorithmes aléatoires, 60h eqTD, L3, ENS, France

Licence: Ana Bušić, Réseaux de communications, 36h, L3, ENS, France

Licence: Ana Bušić, Conception of algorithms and applications, 27h, L3, UPMC Sorbonne Universités, France

Licence: Marc Lelarge, Théorie de l'information et codage, 40h, L3, ENS, France

Master : Anne Bouillard, Probabilistic aspects of computer science, 15h eqTD, M1, ENS Cachan, France

Master : Anne Bouillard, Introduction to tropical mathematics, 32h eq TD, Tokyo institute of technilogy, Japan.

Master: Ana Bušić, Foundations of network models, 14h, M2 MPRI, France

Master: Marc Lelarge, Algorithmique des réseaux sociaux, 40h, M1, ENS, France

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

Doctorat: Alexandre Proutière, Invited short course at IIT Bombay, Decentralized learning in repeated games and network optimisation, 4h, IIT Bombay, India

9.2.2. Supervision

PhD: Tien Viet Nguyen, On the modelling of wireless communication networks using non-poisson point processes [65], Ecole Doctorale Sciences Mathématiques de Paris Centre, defense: January 9, 2013, advisor: F. Baccelli.

PhD : Aurore Junier, Analyses de performance et de stabilité des réseaux de télécommunication [60], ENS Cachan (Bretagne), defence: 16 december 2013, supervisors: Anne Bouillard and Claude Jard (Université de Nantes/LINA)

PhD: Mathieu Leconte, Load-balancing and resource-provisioning in large distributed systems [2], EDITE, CIFRE Technicolor, defense: December 18, 2013, advisors: Marc Lelarge and Laurent Massoulié.

PhD in progress :

- Kumar Gaurav, " Convex comparison of network architectures" started in October 2011, adviser B. Błaszczyszyn;
- Miodrag Jovanović, "Evaluation and optimization of the quality perceived by mobile users for new services in cellular networks" started in January 2012, adviser B. Błaszczyszyn;
- Christelle Rovetta, Applications of perfect sampling to queuing networks and random generation of combinatorial objects, from December 2013, co-supervised by Anne Bouillard and Ana Bušić.

9.2.3. Juries

- François Baccelli:
  - David Coupier, Habililation, Université de Lille, Décembre 2013.
  - Nicolas Chenavier, Université de Rouen (Rapporteur), Décembre 2013.
  - Mathieu Leconte, Institut Mines Télécom, Décembre 2013.
- Bartek Błaszczyszynwas a member in PhD jury of: Anaïs Vergne, Telecom ParisTech, 28/11/2013 and Manjesh Kumar Hanawal, Univ. Avignon, 06/11/2013
- Anne Bouillard was part of the jury of the PhD defence of Aurore Junier.
- Marc Lelarge was part of the jury of the PhD defense of Feng Yan, EDITE, September 2013 and Mathieu Leconte, EDITE, December 2013.
- Alexandre Proutière was a member of the jury, Niek Bouman, Technical University in Eindhoven, December 2013.

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[2] M. LECONTE. , *Équilibrage de charge et répartition de ressources dans les grands systèmes distribués*, Telecom ParisTech, December 2013, http://hal.inria.fr/tel-00933645

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