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Project-Team COATI

Combinatorics, Optimization and Algorithms for Telecommunications

IN COLLABORATION WITH: Laboratoire informatique, signaux systèmes de Sophia Antipolis (I3S)

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Networks and Telecommunications

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Project-Team COATI

Keywords: Graph Theory, Distributed Algorithms, Optical Networks, Networks, Wireless Networks

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2. Overall Objectives

2.1. Overall Objectives

COATI is a joint team between Inria Sophia Antipolis - Méditerranée and the I3S laboratory (Informatique Signaux et Systèmes de Sophia Antipolis) which itself belongs to CNRS (Centre National de la Recherche Scientifique) and UNS (Univ. Nice Sophia Antipolis). Its research fields are Algorithmics, Discrete Mathematics, and Combinatorial Optimization, with applications to telecommunication networks.

The objectives of the COATI project-team are to design networks and communication algorithms. In order to meet these objectives, the team studies various theoretical problems in Discrete Mathematics, Graph Theory, and Algorithmics and develops applied techniques and tools, especially for Combinatorial Optimization and Computer Simulation. In particular, COATI (previously MASCOTTE) used in the last years both these theoretical and applied tools for the design of various networks, such as WDM, wireless (radio), satellite, overlay, and peer-to-peer networks. This research has been done within various industrial and international collaborations.

This results also in the production of advanced software such as GRPH and DRMSim, and in the contribution to large open source software such as SageMath.

3. Research Program

3.1. Research Program

Members of COATI have a good expertise in the design and management of wired and wireless backbone, backhaul, broadband, and complex networks. On the one hand, we cope with specific problems such as energy efficiency in backhaul and backbone networks, routing reconfiguration in connection oriented networks (MPLS, WDM), traffic agregation in SONET networks, compact routing in large-scale networks, survivability to single and multiple failures, etc. These specific problems often come from questions of our industrial partners. On the other hand, we study fondamental problems mainly related to routing and reliability that appear in many networks (not restricted to our main fields of applications) and that have been widely studied in the past. However, previous solutions do not take into account the constraints of current networks/traffic such as their huge size and their dynamics. COATI thus puts a significant research effort in the following directions:

- **Energy efficiency** at both the design and management levels. More precisely, we plan to develop accurate modeling of the power consumption of various parts and components of the networks through measurement done in collaboration with industrial partners (Alcatel-Lucent, 3Roam, Orange labs, etc.). Then, we shall propose new designs of the networks and new routing algorithms in order to lower the power consumption.
- **Larger networks:** Another challenge one has to face is the increase in size of practical instances. It is already difficult, if not impossible, to solve practical instances optimally using existing tools. Therefore, we will have to find new ways to solve problems using reduction and decomposition methods, characterization of polynomial instances (which are surprisingly often the practical ones), or algorithms with acceptable practical performances.
- **Stochastic behaviors:** Larger topologies mean frequent changes due to traffic and radio fluctuations, failures, maintenance operations, growth, routing policy changes, etc. We aim at including these stochastic behaviors in our combinatorial optimization process to handle the dynamics of the system and to obtain robust designs of networks.

4. Application Domains

4.1. Telecommunication networks

COATI is mostly interested in telecommunications networks. Within this domain, we consider applications that follow the needs and interests of our industrial partners, in particular Orange Labs or Alcatel-Lucent Bell-Labs, but also SMEs like 3-Roam and Avisto.

We focus on the design and management of heterogeneous networks. The project has kept working on the design of backbone networks (optical networks, radio networks, IP networks). We also study routing algorithms such as dynamic and compact routing schemes in the context of the FP7 EULER leaded by Alcatel-Lucent Bell-Labs (Belgium), and the evolution of the routing in case of any kind of topological modifications (maintenance operations, failures, capacity variations, etc.).

4.2. Other domains

Our combinatorial tools may be well applied to solve many other problems in various areas (transport, biology, resource allocation, chemistry, smart-grids, speleology, etc.) and we intend to collaborate with teams of these other domains.

For instance, we have recently started a collaboration in Structural Biology with EPI ABS (Algorithms Biology Structure) from Sophia Antipolis (described in Section 6.2). Furthermore, we are also working on robot moving problems coming from Artificial Intelligence/Robotic with Xavier Defago (Associate Professor at Japan Advanded Institute of Science and Technology, Japan).

5. Software and Platforms

5.1. Grph

Participants: David Coudert, Luc Hogie [correspondant], Aurélien Lancin, Issam Tahiri, Michel Syska.

Around 20,000 lines of code, developed in Java, and licensed under LGPL. See http://grph.inria.fr.

The objective of GRPH is to provide researchers and engineers a suitable graph library for graph algorithms experimentation and network simulation. GRPH is primarily a software library, but it also comes with a set of executable files for user interaction and graph format conversion; as such, it can be used autonomously. Performance and accessibility are the primary targets of the GRPH library. It allows manipulating large graphs (millions of nodes). Its model considers mixed graphs composed of directed and undirected simple- and hyper-edges. GRPH comes with a collection of graph algorithms which is regularly augmented.

GRPH includes bridges to other graph libraries such as JUNG, JGraphT, CORESE (a software developed by the WIMMICS team Inria-I3S), LAD (Christine Solnon, LIRIS), Nauty (Brendan D. McKay), SageMath, as well as specific algorithms developed by Matthieu Latapy and Jean-Loup Guillaume (LIP6), etc.

In 2013, we have added several graph algorithms to GRPH (e.g., subgraph isomorphism, subgraph search as sets or regular expressions, transitive closure, etc.). In particular, a significant effort has been put on the support for paths with multiple data-structures for more efficient in-memory representation of paths, and the implementation of algorithms for the enumeration of paths, the characterization of paths, the computation of the k-shortest paths, etc. Furthermore, we have improved the support of weigths in graphs and developed software bridges to SageMath and OGDF. We have also added several models (link-failures, node mobility) for graph dynamics using the discrete-event simulator included in GRPH, as well as models for the development of decentralized algorithms (useful for instance for the simulation of routing schemes). Finally, we have redesigned the website which now includes a forum gathering the community of users.

5.2. SageMath

Participant: David Coudert.

Sagemath is a free open-source mathematics software aiming at becoming an alternative to Maple and Matlab. Initially created by William Stein (Professor of mathematics at Washington University), Sagemath is currently developed by more than 180 contributors around the world (mostly researchers) and its source code, developed in Python, Cython, and C++, has reached 350 MB.

It is of interest for COATI members because it combines a large collection of graph algorithms with various libraries in algebra, calculus, combinatorics, linear programming, statistics, etc. We use SageMath for quickly testing algorithms, analyzing graphs, and disseminating algorithms. We also use it for teaching purposes in the Master 2 IFI, stream UBINET.

In 2013, David Coudert has contributed to the development of the SageMath releases 5.0 to 6.0 with 10 patches (from bug fix to advanced graph algorithms) and participated to the reviewing process of more than 20 patches that are now part of the standard distribution.

5.3. DRMSim

Participants: David Coudert, Luc Hogie [correspondant], Aurélien Lancin, Nicolas Nisse, Issam Tahiri.

Around 45,000 lines, developed in Java, collaboration between COATI, LaBRI, and Alcatel-Lucent Bell labs.

DRMSim relies on a discrete-event simulation engine aiming at enabling the large-scale simulations of routing models. DRMSim is developped in the framework of the FP7 EULER project. It proposes a general routing model which accommodates any network configuration. Aside to this, it includes specific models for Generalized Linear Preference (GLP), and k-chordal network topologies, as well as implementations of routing protocols, including a previously defined routing protocol and lightweight versions of BGP (Border Gateway Protocol).

The metric model takes measures along a discrete-event simulation which can be performed in many ways.

Commonly, a simulation campaign consists in iterating over the set of combinations of parameter values, calling the simulation function for every combination. These combinations are most often complex, impeding their description by a set of mathematical functions. Thus DRMSim provides a simulation methodology that describes (programmatically) the way a simulation campaign should be conducted.

DRMSim stores on disk every step of the execution of a simulation campaign. In a simulation campaign, simulation runs are independent (no simulation depends on the result computed by another simulation). Consequently they can be executed in parallel. Because one simulation is most likely to use large amount of memory and to be multi-threaded, parallelizing the simulation campaign on one single computer is a poor parallelization scheme. Instead, we currently work at enabling the remote parallel execution of several simulation runs, with the same distribution framework that is used in the GRPH library.

DRMSim relies on the Mascsim abstract discrete-event simulation framework, the GRPH library and the Java4Unix integration framework.

In 2013, the work on DRMSim consisted (1) in the implementation of a full support for dynamic networks, including topological modifications and evolving transfer loads in the simulated network. The implementation of the BGP protocol was updated so as to support these dynamic properties. (2) This implementation of BGP was also augmented with a framework enabling its dynamic profiling. (3) Finally DRMSim does no longer relies on the Dipergrafs library. Instead it now uses GRPH, which brings better performance, stability and a broader set of graph algorithms.

See also the web page http://drmsim.gforge.inria.fr/.

5.4. Utilities

5.4.1. P2PVSim

Participant: Remigiusz Modrzejewski [correspondant].

Around 12,000 lines, developed in Python.

P2PVSim is a discrete-event simulator created for analyzing theoretical properties of peer-to-peer live video streaming algorithms. Implemented in Python it was designed with clarity and extensibility in mind from the beginning. It is capable of simulating overlays of a few thousands of peers. Multiple control protocols have been implemented. At the same time, a lot of work was put into the performance and scalability aspects of the software. Currently it is meant for simulating overlays of a few thousand peers running multiple control protocols that have been implemented. And in 2012, a distributed version of P2PVSim was developed running on an arbitrary number of computers. It has been so far used with success on a dozen computers with multiple cores all located in the same LAN.

5.4.2. Papareto

Participant: Luc Hogie [correspondant].

About 500 lines, developed in Java.

PAPARETO is a Java framework for the development of evolutionary solutions to computational problems. The primary motivation for developing an evolutionary framework was to give the GRPH library the ability to generate particular graph instances. Papareto differs from other evolutionary frameworks (ECJ, WatchMaker, JGAP, etc) in the following ways:

- it is *multi-objective*;
- it is *not a genetic algorithms (GAs)* framework because it manipulates objects *as is*. It does not consider their chromosomes representation. Performance consequently is no longer impacted by the computational cost of encoding/decoding;
- it *parallelizes* the creation and the evaluation of a new generation, adaptively to the evolving load of the computer;
- it is *self-adaptive* in the sense that it dynamically evaluates the performance of the crossover and mutation operators, then gives greater priority to most efficient ones;
- it is *easy to use*, by exposing the cleanest and more natural API possible and the minimal set of functionality enabling researchers and engineers to perform evolutionary computing;

See also the webpage http://www.i3s.unice.fr/~hogie/papareto/.

5.4.3. Toools

Participants: Luc Hogie [correspondant], Aurélien Lancin.

Around 3,000 lines, developed in Java.

TOOOLS is a general purpose Java toolbox which, much like Google Guava and Apache Commons, aims at providing classes useful in daily programming tasks. It focuses on the following topics:

- runtime (threads, control of parallel executions of SIMD code, execution of external processes, management of I/O operations, piping);
- input/output files (a complete, easier to use and more complete new model for files on disk is provided) and streams;
- reflection, including dynamic loading of classes, classpath management, Java beans, and access to the source code at runtime;
- application configuration files (parsing, querying, saving);
- plain text, XML;
- collections, including Java collection utilities and efficient sets of primitive integers;
- mathematical and statistical operations.

See also the webpage http://www-sop.inria.fr/members/Luc.Hogie/toools/.

5.4.4. Other software

We ensure the maintenance of various tools developped in the past:

Java4unix a software glue for the integration of Java applications intro the UNIX environment; http://www-sop.inria.fr/members/Luc.Hogie/java4unix/;

Jalinopt a Java toolkit for linear optimization; http://www-sop.inria.fr/members/Luc.Hogie/jalinopt/;

JavaFarm a minimal middleware infrastructure for practical distributed computing; see http://www-sop.inria.fr/members/Luc.Hogie/javafarm/;

Macsim a discrete event simulation engine use in the DRMSIM routing model simulator; http://www-sop.inria.fr/mascotte/software/mascsim/;

Jaseto a Java toolkit for the XML (de)serialization of Java objects; http://www-sop.inria.fr/members/Luc.Hogie/jaseto/;

6. New Results

6.1. Network Design and Management

Participants: Julio Araújo, Jean-Claude Bermond, Luca Chiaraviglio, David Coudert, Frédéric Giroire, Alvinice Kodjo, Aurélien Lancin, Remigiusz Modrzejewski, Christelle Molle-Caillouet, Joanna Moulierac, Nicolas Nisse, Stéphane Pérennes, Truong Khoa Phan, Ronan Pardo Soares, Issam Tahiri.

6.1.1. Optimization in backbone networks

6.1.1.1. Shared Risk Link Group

The notion of Shared Risk Link Groups (SRLG) has been introduced to capture survivability issues where some links of a network fail simultaneously. In this context, the diverse routing problem is to find a set of pairwise SRLG-disjoint paths between a given pair of end nodes of the network. This problem has been proved NP-complete in general and some polynomial instances have been characterized.

In [33], [32], we investigate the diverse-routing problem in networks where the SRLGs are localized and satisfy the *star property*. This property states that a link may be subject to several SRLGs, but all links subject to a given SRLG are incident to a common node. We first provide counterexamples to the polynomial-time algorithm proposed in the literature for computing a pair of SRLG-disjoint paths in networks with SRLGs satisfying the star property, and then prove that this problem is in fact NP-complete. We have also characterized instances that can be solved in polynomial time or are fixed parameter tractable, in particular when the number of SRLGs is constant, the maximum degree of the vertices is at most 4, and when the network is a directed acyclic graph. Moreover, we have considered the problem of finding the maximum number of SRLG-disjoint paths in networks with SRLGs satisfying the star property. We have proved that such problem is NP-hard and hard to approximate. Then, we have provided exact and approximation algorithms for relevant subcases.

6.1.1.2. Wavelength assignment in WDM networks

Let $\mathcal{P}$ be a family of directed paths in a directed graph G. The load of an arc is the number of directed paths containing this arc. Let $\pi(G,\mathcal{P})$ be the maximum of the load of all the arcs and let $w(G,\mathcal{P})$ be the minimum number of wavelengths (colours) needed to colour $\mathcal{P}$ in such a way that two directed paths with the same wavelength are arc-disjoint. These two parameters correspond respectively to the clique number and the chromatic number of the associated conflict graph, and $\pi(G,\mathcal{P}) \leq w(G,\mathcal{P})$. It was known that there exists directed acyclic graphs (DAGs) such that the ratio between $w(G,\mathcal{P})$ and $w(G,\mathcal{P})$ is arbitrarily large. In [18], solving a conjecture of an earlier article, we show that the same is true for a very restricted class of DAGs, the UPP-DAGs, those for which there is at most one directed path from a vertex to another. We also characterized the DAGs such that $\pi(G,\mathcal{P}) = w(G,\mathcal{P})$ for all families of directed paths.

6.1.1.3. Mutli-operators microwave backhaul networks

In [35], we consider the problem of sharing the infrastructure of a backhaul network for routing. We investigate on the revenue maximization problem for the physical network operator (PNO) when subject to stochastic traffic requirements of multiple virtual network operators (VNO) and prescribed service level agreements (SLA). We use robust optimization to study the tradeoff between revenue maximization and the allowed level of uncertainty in the traffic demands. This mixed integer linear programming model takes into account end-to-end traffic delays as example of quality-of-service requirement in a SLA. To show the effectiveness of our model, we present a study on the price of robustness, i.e. the additional price to pay in order to obtain a feasible solution for the robust scheme, on realistic scenarios.

6.1.2. Energy efficiency

With one third of the world population online in 2013 and an international Internet bandwidth multiplied by more than eight since 2006, the ICT sector is a non-negligible contributor of worldwide greenhouse gases emissions and power consumption. Indeed, power consumption of telecommunication networks has become a major concern for all the actors of the domain, and efforts are made to reduce their impact on the overall figure of ICTs, and to support its foreseen growth in a sustainable way. In this context, the contributors of the European Network of Excellence TREND have developed innovative solutions to improve the energy efficiency of optical networks summarized in [45].

6.1.2.1. Energy aware routing with redundancy elimination

Many studies have shown that energy-aware routing (EAR) can significantly reduce energy consumption of a backbone network. Redundancy Elimination (RE) techniques provide a complementary approach to reduce the amount of traffic in the network. In particular, the GreenRE model combines both techniques, offering potentially significant energy savings.

In [44], we enhance the MIP formulation proposed in [75] for the GreenRE model. We derive cutting planes, extending the well-known cutset inequalities, and report on preliminary computations.

In [37], we propose a concept for respecting uncertain rates of redundant traffic within the GreenRE model, closing the gap between theoretical modeling and drawn-from-life data. To model redundancy rate uncertainty, the robust optimization approach in [73] is adapted and the problem is formally defined as mixed integer linear program. An exemplary evaluation of this concept with real-life traffic traces and estimated fluctuations of data redundancy shows that this closer-to-reality model potentially offers significant energy savings in comparison to GreenRE and EAR.

6.1.2.2. Energy Efficient Content Distribution

The basic protocols of the Internet are point-to-point in nature. However, the traffic is largely broadcasting, with projections stating that as much as 80-90% of it will be video by 2016. This discrepancy leads to an inefficiency, where multiple copies of essentially the same messages travel in parallel through the same links. We have studied approaches to mitigate this inefficiency and reduce the energy consumption of future networks, in particular in [13].

In [29], we study the problem of reducing power consumption in an Internet Service Provider (ISP) network by designing the content distribution infrastructure managed by the operator. We propose an algorithm to optimally decide where to cache the content inside the ISP network. We evaluate our solution over two case studies driven by operators feedback.

Recently, there is a trend to introduce content caches as an inherent capacity of network equipment, with the objective of improving the efficiency of content distribution and reducing network congestion. In [57], [46], [29], we study the impact of using in-network caches and content delivery network (CDN) cooperation on an energy-efficient routing. Experimental results show that by placing a cache on each backbone router to store the most popular content, along with well choosing the best content provider server for each demand to a CDN, we can save up to 23% of power in the backbone.

6.1.3. Distributed systems

6.1.3.1. Distributed Storage systems.

In a P2P storage system using erasure codes, a data block is encoded in many redundancy fragments. These fragments are then sent to distinct peers of the network. In [24], we study the impact of different placement policies of these fragments on the performance of storage systems.

In [39], we propose a new analytical framework that takes into account the correlation between data reconstructions when estimating the repair time and the probability of data loss. The models and schemes proposed are validated by mathematical analysis, extensive set of simulations, and experimentation using the GRID5000 test-bed platform. This new model allows system designers to operate a more accurate choice of system parameters in function of their targeted data durability.

6.1.3.2. P2P Streaming systems

In [41], [68], we propose and analyze a simple localized algorithm to balance a tree. The motivation comes from live distributed streaming systems in which a source diffuses a content to peers via a tree, a node forwarding the data to its children. Such systems are subject to a high churn, peers frequently joining and leaving the system. It is thus crucial to be able to repair the diffusion tree to allow an efficient data distribution. In particular, due to bandwidth limitations, an efficient diffusion tree must ensure that node degrees are bounded. Moreover, to minimize the delay of the streaming, the depth of the diffusion tree must also be controlled. We propose here a simple distributed repair algorithm in which each node carries out local operations based on its degree and on the subtree sizes of its children.

6.1.4. Data Gathering in Radio Networks

We study the problem of gathering information from the nodes of a radio network into a central node. We model the network of possible transmissions by a graph and consider a binary model of interference in which two transmissions interfere if the distance in the graph from the sender of one transmission to the receiver of the other is d_I or less.

In [19], we give an algorithm to construct minimum makespan transmission schedules for data gathering under the following hypotheses: the communication graph G is a tree network, and no buffering is allowed at intermediate nodes and $d_I \geq 2$. In the interesting case in which all nodes in the network have to deliver an arbitrary positive number of packets, we provide a closed formula for the makespan of the optimal gathering schedule. Additionally, we consider the problem of determining the computational complexity of data gathering in general graphs and show that the problem is NP–complete. On the positive side, we design a simple $(1 + 2/d_I)$-factor approximation algorithm for general networks.

In [59], we focus on the gathering and personalized broadcasting problem in grids. We still consider the non-buffering model. In this setting, though the problem of determining the complexity of computing the optimal makespan in a grid is still open, we present linear (in the number of messages) algorithms that compute schedules for gathering with $d_I = 0, 1, 2$. In particular, we present an algorithm that achieves the optimal makespan up to a small additive constant. Note that, the approximation algorithms that we present also provide approximation up to a ratio 2 for the gathering with buffering. All our results are proved in terms of personalized broadcasting.

In [20], we now allow transmission till a distance d_T and buffering in intermediate nodes. We focus on the specific case where the network is a path with the sink at an end vertex of the path and where the traffic is unitary ($w(u) = 1$ for all u); indeed this simple case appears to be already very difficult. We first give a new lower bound and a protocol with a gathering time that differs only by a constant independent from the length of the path. Then we present a method to construct incremental protocols which are optimal for many values of d_T and d_I (in particular when d_T is prime).

In [50], we focus on gathering uncertain traffic demands in mesh networks with multiple sources and sinks. The scheduling is relaxed into the round weighting problem in which a set of pairwise non-interfering links is called a round, and we seek to successively activate rounds in order to get enough capacity on links to route the demand from the set of sources to the set of sinks. We propose a new robust model considering traffic demand uncertainty, efficiently solved by column generation, and quantify the price of robustness, i.e., the additional cost to pay in order to obtain a feasible solution for the robust scheme.

6.1.5. Routing

6.1.5.1. Routing models evaluation

The Autonomous System (AS)-level topology of the Internet that currently comprises more than 40k ASs, is growing at a rate of about 10% per year. In these conditions, Border Gateway Protocol (BGP), the inter-domain routing protocol of the Internet starts to show its limits, among others in terms of the number of routing table entries it can dynamically process and control. To overcome this challenging situation, the design but also the evaluation of alternative dynamic routing models and their comparison with BGP will be performed by means of simulation. However, existing routing models simulators such as DRMSim, the Dynamic Routing Model Simulator developped in COATI in collaboration with Alcatel-Lucent [72], are limited in terms of the number of routing table entries they can dynamically process and control on a single computer.

In [63], we have conducted a feasibility study of the extension of DRMSim so as to support the Distributed Parallel Discrete Event paradigm. We have studied several distribution models and their associated communication overhead. We have in particular evaluated the expected additional time required by a distributed simulation of BGP (border gate protocol) on topologies with 100k ASes compared to its sequential simulation. We show that such a distributed simulation of BGP is possible with a reasonable time overhead.

6.1.5.2. Complexity of Shortest Path Routing

In telecommunication networks packets are carried from a source s to a destination t on a path that is determined by the underlying routing protocol. Most routing protocols belong to the class of shortest-path routing protocols. For better protection and efficiency, one wishes to use multiple (shortest) paths between two nodes. Therefore the routing protocol must determine how the traffic from s to t is distributed among the shortest paths. In the protocol called OSPF-ECMP (for Open Shortest Path First-Equal Cost Multiple Path) the traffic incoming at every node is uniformly balanced on all outgoing links that are on shortest paths. In [43], [42], we show that the problem of maximizing even a single commodity flow for the OSPF-ECMP protocol cannot be approximated within any constant factor ratio. Besides this main theorem, we derive some positive results which include polynomial-time approximations and an exponential-time exact algorithm.

6.2. Graph Algorithms

Participants: Julio Araújo, Jean-Claude Bermond, David Coudert, Frédéric Havet, Frédéric Giroire, Bi Li, Fatima Zahra Moataz, Christelle Molle-Caillouet, Nicolas Nisse, Ronan Pardo Soares, Stéphane Pérennes.

COATI is also interested in the algorithmic aspects of Graph Theory. In general we try to find the most efficient algorithms to solve various problems of Graph Theory and telecommunication networks. More information on several results presented in this section may be found in R. Soares's thesis [14].

6.2.1. Complexity and Computation of Graph Parameters

We use graph theory to model various network problems. In general we study their complexity and then we investigate the structural properties of graphs that make these problems hard or easy. In particular, we try to find the most efficient algorithms to solve the problems, sometimes focusing on specific graph classes from which the problems are polynomial-time solvable.

6.2.1.1. Parameterized Complexity

Parameterized complexity is a way to deal with intractable computational problems having some parameters that can be relatively small with respect to the input size. This area has been developed extensively during the last decade. More precisely, we consider problems that consist in deciding whether a graph G satisfies some property (i.e., if G belongs to some given family of graphs). For decision problems with input size n and parameter k, the goal is to design an algorithm with running time $f(k).n$, where f depends only on k. Problems for which we can find an optimal algorithm with such time complexity are said to be fixed-parameter tractable (FPT). Equivalently, the goal is to design a polynomial-time algorithm (in k and n) that computes a pair (H,k') where H is a graph (the kernel) with size polynomial in k and $P(G) \leq k$ if and only if $P(H) \leq k'$.

We study the parameterized complexity of the edge-modification problems. Given a graph $G = (V, E)$ and a positive integer k, an edge modification problem for a graph property Π consists in deciding whether there exists a set F of pairs of V of size at most k such that the graph $H = (V, E\Delta F)$ satisfies the property Π. In [25], it is proved that parameterized cograph edge-modification problems have cubic vertex kernels whereas polynomial kernels are unlikely to exist for the P_l-free edge-deletion and the C_l-free edge-deletion problems for $l \geq 7$ and $l \geq 4$ respectively.

We also design a unified parameterized algorithm for computing various widths of graphs (such as branched tree-width, branch-width, cut-width, etc.) [60].

6.2.1.2. Convexity in Graphs

The geodesic convexity of graphs naturally extends the notion of convexity in euclidean metric spaces. A set S of vertices of a graph $G = (V, E)$ is *convex* if any vertex on a shortest path between two vertices of S also belongs to S. The *convex hull* of $S \subset V$ is the smallest convex set containing S. Finally, a *hull set* of a graph is a set of vertices whose convex hull is V. The hull number of a graph G is the minimum size of a hull set in G. In [16] , we prove that computing the hull number is NP-complete in bipartite graphs. We also provide bounds and design various polynomial-time algorithms for this problem in different graph classes such as co-bipartite graphs, P_4-sparse graphs, etc. In [30], we first show a polynomial-time algorithm to compute the hull number of any P_5-free triangle-free graph. Then, we present four reduction rules based on vertices with the same neighborhood. We use these reduction rules to propose a fixed-parameter tractable algorithm to compute the hull number of any graph G, where the parameter is the size of a vertex cover of G or, more generally, its neighborhood diversity. We also use these reductions to characterize the hull number of the lexicographic product of any two graphs.

6.2.1.3. Hyperbolicity

The Gromov hyperbolicity is an important parameter for analyzing complex networks since it expresses how the metric structure of a network looks like a tree. In other words, it provides bounds on the stretch resulting from the embedding of a network topology into a weighted tree. It is therefore used to provide bounds on the expected stretch of greedy-routing algorithms in Internet-like graphs. However, the best known algorithm for computing this parameter has time complexity in $O(n^{3.69})$, which is prohibitive for large-scale graphs. In [36], we proposed a novel algorithm for determining the hyperbolicity of a graph that is scalable for large graphs. The time complexity of this algorithm is output-sensitive and depends on the shortest-path distances distribution in the graph and on the computed value of the hyperbolicity. Although its worst case time complexity is in $O(n^4)$, it is in practice much faster than previous proposals as it uses bounds to cut the search space. This algorithm allowed us for computing the hyperbolicity of all maps of the Internet provided by CAIDA and DIMES.

6.2.2. Graph searching and applications

Pursuit-evasion encompasses a wide variety of combinatorial problems related to the capture of a fugitive residing in a network by a team of searchers. The goal consists in minimizing the number of searchers required to capture the fugitive in a network and in computing the corresponding capture strategy. We investigated several variants of these games.

6.2.2.1. Variants of graph searching.

We study non-deterministic graph searching where the searchers have to capture an invisible fugitive but can see him a bounded number of times. This variant generalizes the notion of pathwidth and treewidth of graphs. In this setting, we provide a polynomial-time algorithm that approximates the minimum number of searchers needed in trees, up to a factor of two [56].

In [34], [61], we define another variant of graph searching, where searchers have to capture an invisible fugitive with the constraint that no two searchers can occupy the same node simultaneously. This variant seems promising for designing approximation algorithms for computing the pathwidth of graphs. The main contribution in [34], [61] is the characterization of trees where k searchers are necessary and sufficient to win. Our characterization leads to a polynomial-time algorithm to compute the minimum number of searchers needed in trees.

We also study graph searching in directed graphs. We prove that the graph processing variant is monotone which allows us to show its equivalence with a particular digraph decomposition [47].

6.2.2.2. Surveillance Game and Fractional Game.

A surprising application of some variant of pursuit-evasion games is the problem for a web-browser to download documents in advance while an internaut is surfing on the Web. In a previous work, we model this problem as a Pursuit-evasion game called Surveillance game. In [40], [67], we continue our study of the Surveillance game. We provide some bounds on the connected and online variants of this game. In particular, we show that, in the online variant (when the searchers discover the graph during the game), the best strategy is the trivial one that consists in downloading the document in the neighborhood of the position of the internaut.

In [69], [48], [52], we define a framework generalizing and relaxing many games (including the Surveillance game) where Players use fractions of their token at each turn. We design an algorithm for solving the fractional games. In particular, our algorithm runs in polynomial-time when the length of the game is bounded by 2 (in contrast, computing the surveillance game is NP-hard even when the game is limited to two turns). For some games, we also prove that the fractional variant provides some good approximation. This direction of research seems promising for solving many open problems related to Pursuit-evasion games.

6.2.2.3. Robots in anonymous networks.

Motivated by the understanding of the limits of distributed computing, we consider a recent model of robot-based computing which makes use of identical, memoryless mobile robots placed on nodes of anonymous graphs. The robots operate in Look-Compute-Move cycles that are performed asynchronously for each robot. In particular, we consider various problems such as graph exploration, graph searching and gathering in various graph classes. We provide a new distributed approach which turns out to be very interesting as it neither completely falls into symmetry-breaking nor into symmetry-preserving techniques. We proposed a general approach [38], [66] to solve the three problems in rings even in case of symmetric initial configurations.

6.2.3. Algorithm design in biology

In COATI, we have recently started a collaboration with EPI ABS (Algorithms Biology Structure) from Sophia Antipolis on “minimal connectivity complexes in mass spectrometry based macro-molecular complex reconstruction” [28], [55]. This problem turns out to be a minimum color covering problem (minimum number of colors to cover colored edges with connectivity constraints on the subgraphs induced by the colors) of the edges of a graph, and is surprizingly similar to a capacity maximization problem in a multi-interfaces radio network we were studying.

6.3. Structural Graph Theory

Participants: Julio Araújo, Jean-Claude Bermond, Frédéric Havet, Nicolas Nisse, Ana Karolinna Maia de Oliveira, Stéphane Pérennes.

6.3.1. Graph colouring and applications

Graph colouring is a central problem in graph theory and it has a huge number of applications in various scientific domains (telecommunications, scheduling, bio-informatics, ...). We mainly study graph colouring problems that model ressource allocation problems.

6.3.1.1. Backbone colouring

A well-known channel assignment problem is the following: we are given a graph G, whose vertices correspond to transmitters, together with an edge-weghting w. The weight of an edge corresponds to the minimum separation between the channels on its endvertices to avoid interferences. (If there is no edge, no separation is required, the transmitters do not interfere.) We need to assign positive integers (corresponding to channels) to the vertices so that for every edge e the channels assigned to its endvertices differ by at least $w(e)$. The goal is to minimize the largest integer used, which corresponds to minimizing the *span* of the used bandwidth.

We studied a particular, yet quite general, case, called *backbone colouring*, in which there are only two levels of interference. So we are given a graph G and a subgraph H, called *the backone*. Two adjacent vertices in H must get integers at least q apart, while adjacent vertices in G must get integers at distance at least 1. The minimum span is this case is called the *q-backbone chromatic number* and is denoted $BBC_q(G, H)$. Backbone forests in planar graphs are of particular interests. In [22], we prove that if G is planar and T is a tree of diameter at most 4, then $BBC_2(G, T) \leq 6$ hence giving an evidence to a conjecture of Broersma et al. [74] stating that the same holds if T has an arbitrary diameter.

6.3.1.2. *Weighted colouring*

We also studied weighted colouring which models various problems of shared resources allocation. Given a vertex-weighted graph G and a (proper) r -colouring $c = \{C_1, ..., C_r\}$ of G , the *weight* of a colour class C_i is the maximum weight of a vertex coloured i and the *weight* of c is the sum of the weights of its colour classes. The objective of the Weighted Colouring Problem is, given a vertex-weighted graph G , to determine the minimum weight of a proper colouring of G, that is, its *weighted chromatic number*. In [17], we prove that the Weighted Colouring Problem admits a version of Hajós' Theorem and so we show a necessary and sufficient condition for the weighted chromatic number of a vertex-weighted graph G to be at least k, for any positive real k. The Weighted Colouring Problem problem remains NP-complete in some particular graph classes as bipartite graphs. In their seminal paper [77], Guan and Zhu asked whether the weighted chromatic number of bounded tree-width graphs (partial k-trees) can be computed in polynomial-time. Surprisingly, the time-complexity of computing this parameter in trees is still open. We show [58] that, assuming the Exponential Time Hypothesis (3-SAT cannot be solved in sub-exponential time), the best algorithm to compute the weighted chromatic number of n-node trees has time-complexity $n^{\Theta(\log n)}$. Our result mainly relies on proving that, when computing an optimal proper weighted colouring of a graph G, it is hard to combine colourings of its connected components, even when G is a forest.

6.3.1.3. *On-line colouring*

Since many applications, and in particular channel assignment problems, must be solved on-line, we studied on-line colouring algorithms. The most basic and most widespread of them is the greedy algorithm. The largest number of colours that can be given by the greedy algorithm on some graph. is called its *Grundy number* and is denoted $\Gamma(G)$. Trivially $\Gamma(G) \leq \Delta(G) + 1$, where $\Delta(G)$ is the maximum degree of the graph. In [26], we show that deciding if $\Gamma(G) \leq \Delta(G)$ is NP-complete. We then show that deciding if $\Gamma(G) \geq |V(G)| - k$ is fixed-parameter tractable with respect to the parameter k. We also gave similar complexity results on b-colourings, which is a manner of improving colourings on-line.

In [27], we study a game version of greedy colouring. Given a graph G, two players, Alice and Bob, alternate their turns in choosing uncoloured vertices to be coloured. Whenever an uncoloured vertex is chosen, it is coloured by the least positive integer not used by any of its coloured neighbors. Alice's goal is to minimize the total number of colours used in the game, and Bob's goal is to maximize it. The *game Grundy number* of G is the number of colours used in the game when both players use optimal strategies. It is proved in this paper that the maximum game Grundy number of forests is 3, and the game Grundy number of any partial 2-tree is at most 7.

6.3.1.4. *Enumerating edge-colourings and total colourings*

With the success of moderately exponential algorithms, there is an increasing interest for enumeration problems, because of their own interest but also because they might be crucial to solve optimization problems. In [21], we are interested in computing the number of edge colourings and total colourings of a connected graph. We prove that the maximum number of k-edge-colourings of a connected k-regular graph on n vertices is $k \cdot ((k-1)!)^{n/2}$. Our proof is constructive and leads to a branching algorithm enumerating all the k-edge-colourings of a connected k-regular graph in time $O^*(((k-1)!)^{n/2})$ and polynomial space. In particular, we obtain a algorithm to enumerate all the 3-edge-colourings of a connected cubic graph in time $O^*(2^{n/2}) = O^*(1.4143^n)$ and polynomial space. This improves the running time of $O^*(1.5423^n)$ of the algorithm of Golovach et al. [76]. We also show that the number of 4-total-colourings of a connected cubic graph is at most $3 \cdot 2^{3n/2}$. Again, our proof yields a branching algorithm to enumerate all the 4-total-colourings of a connected cubic graph.

6.3.2. Directed graphs

Graph theory can be roughly partitioned into two branches: the areas of undirected graphs and directed graphs (digraphs). Even though both areas have numerous important applications, for various reasons, undirected graphs have been studied much more extensively than directed graphs. One of the reasons is that many problems for digraphs are much more difficult than their analogues for undirected graphs.

6.3.2.1. Finding a subdivision of a digraph

One of the cornerstones of modern (undirected) graph theory is minor theory of Robertson and Seymour. Unfortunately, we cannot expect an equivalent for directed graphs. Minor theory implies in particular that, for any fixed F, detecting a subdivision of a fixed graph F in an input graph G can be performed in polynomial time by the Robertson and Seymour linkage algorithm. In contrast, the analogous subdivision problem for digraph can be either polynomial-time solvable or NP-complete, depending on the fixed digraph F. In a previous paper, we gave a number of examples of polynomial instances, several NP-completeness proofs as well as a number of conjectures and open problems. In [71], we conjecture that, for every integer k greater than 1, the directed cycles of length at least k have the Erdős-Pósa Property : for every n, there exists an integer t_n such that for every digraph D, either D contains n disjoint directed cycles of length at least k, or there is a set T of t_n vertices that meets every directed cycle of length at least k. This generalizes a celebrated result of Reed, Robertson, Seymour and Thomas which is the case $k = 2$ of this conjecture. We prove the conjecture for $k = 3$. We also show that the directed k-Linkage problem is polynomial-time solvable for digraphs with circumference at most 2. From these two results, we deduce that if F is the disjoint union of directed cycles of length at most 3, then one can decide in polynomial time if a digraph contains a subdivision of F.

6.3.2.2. Oriented trees in digraphs

Let $f(k)$ be the smallest integer such that every $f(k)$-chromatic digraph contains every oriented tree of order k. Burr proved $f(k) \leq (k-1)^2$ in general, and he conjectured $f(k) = 2k - 2$. Burr also proved that every $(8k - 7)$-chromatic digraph contains every antidirected tree. We improve both of Burr's bounds. We show [15] that $f(k) \leq k^2/2 - k/2 + 1$ and that every antidirected tree of order k is contained in every $(5k - 9)$-chromatic digraph. We also make a conjecture that explains why antidirected trees are easier to handle. It states that if $|E(D)| > (k - 2)|V(D)|$, then the digraph D contains every antidirected tree of order k. This is a common strengthening of both Burr's conjecture for antidirected trees and the celebrated Erdős-Sós Conjecture. The analogue of our conjecture for general trees is false, no matter what function $f(k)$ is used in place of $k - 2$. We prove our conjecture for antidirected trees of diameter 3 and present some other evidence for it. Along the way, we show that every acyclic k-chromatic digraph contains every oriented tree of order k and suggest a number of approaches for making further progress on Burr's conjecture.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Grants with Industry

7.1.1. Contract CIFRE with Orange Labs, 02/2011 - 01/2014

Participants: Jean-Claude Bermond, Sébastien Félix.

"Convention de recherche encadrant une bourse CIFRE" on the topic *Smart Transports: optimisation du trafic dans les villes*.

7.1.2. Contract CIFRE with KONTRON, 11/2011 - 10/2014

Participants: Michel Syska, Mohamed Amine Bergach.

"Convention de recherche encadrant une bourse CIFRE" on the topic *Graphic Processing Units for Signal Processing* with joint supervision with AOSTE project.

7.1.3. ADR Network Science, joint laboratory Inria / Alcatel-Lucent Bell-labs France, 01/2013 - 12/2015

Participants: David Coudert, Aurélien Lancin, Bi Li, Nicolas Nisse.

COATI is part of the join laboratory Inria / Alcatel-Lucent Bell-labs France within the ADR Network Science and works on the fast computation of topological properties (hyperbolicity, covering, etc.) [36].

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

8.1.1.1. ANR Blanc AGAPE, 10/2009-09/2013

Participants: David Coudert, Frédéric Havet, Ana Karolinna Maia de Oliveira, Nicolas Nisse, Stéphane Pérennes, Michel Syska.

The project AGAPE (Parameterized and exact graph algorithms) is led by COATI and implies also LIRMM (Montpellier) and LIFO (Orléans). The aim of AGAPE is to develop new techniques to solve exactly NP-hard problems on graphs. To do so, we consider two approaches which are closely related ways to reduce the combinatorial explosion of NP-hard problems: moderately exponential exact algorithms and fixed-parameter tractability.

(http://www-sop.inria.fr/mascotte/Contrats/Agape.php)

8.1.2. GDR Actions

8.1.2.1. Action ResCom, ongoing (since 2006)

Réseaux de communications, working group of GDR ASR, CNRS.

(http://rescom.asr.cnrs.fr/)

8.1.2.2. Action Graphes, ongoing (since 2006)

Action Graphes, working group of GDR IM, CNRS.

(http://www.labri.fr/perso/raspaud/pmwiki/pmwiki.php)

8.2. European Initiatives

8.2.1. FP7 Projects

8.2.1.1. EULER

Participants: David Coudert, Luc Hogie, Aurélien Lancin, Bi Li, Nicolas Nisse, Stéphane Pérennes, Issam Tahiri.

Title: EULER (Experimental UpdateLess Evolutive Routing)
Type: COOPERATION (ICT)
Defi: Future Internet Experimental Facility and Experimentally-driven Research
Instrument: Specific Targeted Research Project (STREP)
Duration: October 2010 - June 2014
Partners: Alcatel-Lucent Bell (leader) (Antwerp, Belgique), iMind (Ghent, Belgium), UCL (Louvain, Belgium), RACTI (Patras, Grece), UPC (Barcelona, Spain), UPMC (ComplexNetworks, Paris 6), Inria (COATI, GANG, CEPAGE).Coordinator: ALCATEL-LUCENT (Belgium)
STREP EULER (Experimental UpdateLess Evolutive Routing) is part of FIRE (Future Internet Research and Experimentation) objective of FP7. It aims at finding new paradigms to design, develop, and validate experimentally a distributed and dynamic routing scheme suitable for the future Internet and its evolution. COATI is the leader of WP3 on Topology Modelling and Routing scheme experimental analysis.
See also: http://www-sop.inria.fr/mascotte/EULER/wiki/

8.2.2. Collaborations in European Programs, except FP7

8.2.2.1. PHC PROCOPE (with Discrete Optimization group of RWTH Aachen University), 01/2011-06/2013

Participants: Christelle Molle-Caillouet, David Coudert, Alvinice Kodjo, Issam Tahiri, Truong Khoa Phan.

Bilateral collaboration funded by the french ministry of foreign affairs (MAE), the french ministry of research and education (MESR), and the Deutscher Akademischer Austauschdienst (DAAD). The funding covers scientific visits.

"Défis algorithmiques dans les réseaux de communication". The purpose of the project is to exchange expertise between the discrete optimization group of RWTH Aachen University and the COATI team at Inria Sophia-Antipolis and to address algorithmic problems in communication networks.

8.3. International Initiatives

8.3.1. Inria Associate Teams

8.3.1.1. AlDyNet

Title: Algorithm for large and Dynamic Networks

Inria principal investigator: Nicolas Nisse

International Partner (Institution - Laboratory - Researcher):

Universidad Adolfo Ibañez, Santiago, Chile
Facultad de Ingeniería y Ciencias
Karol Suchan

Duration: 2013 - 2015

See also: http://team.inria.fr/coati/projects/aldynet/

The main goal of this Associate Team is to study the structure of networks (modeled by graphs) to design both efficient distributed algorithms and reliable network topologies suitable to applications. We are interested both in large-scale (Facebook, Internet, etc.) and in smaller networks (e.g., WDM) that handle heavy traffic. More precisely, we aim at designing new techniques of distributed and localized computing to test structural properties of networks and to compute structures (e.g., decompositions) to be used in applications. Concerning the applications, we will first focus on routing and subgraph packing problems.

There are two main objectives:

- Find efficient localized algorithms to test certain graph properties or to prove that no such algorithms exist. We will formalize several distributed computing models and analyze which properties can and which cannot be tested in them.
- Define graph properties – computable or approximable in distributed systems – such as structures/decompositions/representations. The driving idea is to combine several well studied graph properties in order to obtain more specific structures which we hope to be more easily computable.

To verify the practical efficiency of our results, the designed algorithms will be implemented and compared to existing ones. For this purpose, a particular effort will be put to design and implement algorithms to generate graphs that satisfy properties of interest, in order to use them to test the algorithms.

The originality of the proposal is to combine powerful tools of graphs theory (e.g., FPT complexity) and of combinatorial optimization (Mixed Integer Programming) with distributed computing. One challenge here is to balance between the degree of locality of desired algorithms and the relevance of properties that may be computed.

8.3.2. Inria International Partners

8.3.2.1. ANR International Taiwan GRATEL, 01/2010 – 12/2013

Participants: Jean-Claude Bermond, Frédéric Havet.

GRATEL (Graphs and Telecomunications) has been started in collaboration with LABRI Bordeaux, UJF Grenoble and three partners in Taiwan: Sun Yat-sen University, the National Taiwan University and Academia Sinica.

(https://gratel.labri.fr/pmwiki.php?n=Main.HomePage)

8.3.3. Participation In other International Programs

Inria FUNCAP (Inria-FAP): ALERTE (ALgorithmes Efficaces pour les Réseaux de TElécommunications), with Pargo Team, Universidade Federal do Ceará, Brazil, 07/2011-07/2013.

Action ECOS-SUD: ALgorithmes Distribués pour le calcul de la structure des réseaux, with Chile, 2013-2015.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

Jørgen Bang-Jensen: Univ. Southern Denmark, Odensee, Denmark, from October 11 to November 2, 2013 (3 weeks);

Gianlorenzo D'Angelo: Univ. degli studi di Perugia, Italy, September 9-17, 2013 (2 weeks);

Xavier Défago: Japan Advanced Institute of Science and Technology, Nomi, Ishikawa, Japan, from September 16, 2013 to January 31, 2014 (4.5 months);

Mattia D'Emidio: Univ. L'aquila, Italy, from March 1 to April 30, 2013 (2 months);

Michele Flammini: Univ. of L'Aquila, Italy, from June 22 to July 13, 2013 (3 weeks);

Brigitte Jaumard: Concordia Univ., Montréal, Canada, February 11-22, 2013 (2 weeks);

Mejdi Kaddour: Univ. Oran, Algeria, December 6-13, 2013 (1 week);

Takako Kodate: Tokyo Woman's Christian Univ., Suginami-ku, Tokyo, Japan, from March 21 to April 4, 2013 (2 weeks);

Arie M.C.A. Koster: RWTH Aachen Univ., Germany, February 11-15, 2013 (1 week);

Claudia Linhares-Sales: UFC Fortaleza, Brazil, November 5-11, 2013 (1 week);

Euripides Markou: Univ. Thessaly, Volos, Greece, March 24th-31th (1 week);

Gianpiero Monaco: Univ. L'Aquila, Italy, September 1-8, 2013 (1 week);

Joseph Peters: Simon Frasier Univ., Vancouver, Canada, from January 20 to June 14, 2013 (5 months);

Guido Proietti: Univ. L'Aquila, Italy, September 1-9, 2013 (1 week);

Esteban H. Roman Catafau: Univ. Adolfo Ibañez, Chile, from September 7 to October 6, 2013 (1 month);

Karol Suchan: Univ. Adolfo Ibáñez, Chile, September 7-21, 2013 (2 weeks);

Amel Tandjaoui: Univ. Oran, Algeria, June 12 till July 13, 2013 (1 month);

Joseph Yu: Abbotsford and SFU, Vancouver, Canada, from March 1 to April 19, 2013 (1 month 1/2);

8.4.1.1. Internships

Guillaume Ducoffe: ENS Cachan, from March 18, 2013 until August 31, 2013, and since October 15, 2013;

Rennan Ferreira Dantas: Univ. Federal do Ceará, Brazil, since November 2013;

Klaus Christoph Jaschan Little: Univ. Adolfo Ibañez, Chile, since December 2013;

Ioannis Lamprou: National and Kapodistrian Univ. Athens, Greece, from March 2013 until September 2013;

Christos Papageorgakis: Univ. Central Greece, from January 2013 until July 2013;

Phablo Fernando Soares Moura: Univ. São Paulo (USP), Brazil, from March 2013 until July 2013;

Claudio Soares De Carvalho Neto: Univ. Federal do Ceará, Brazil, since November 2013;

8.4.2. Visits to International Teams

J. Araújo and A.K. Maia: Visit to Simon Fraser Univ., Vancouver, Canada (January 11-February 10, 2013).

J-C. Bermond: LRI, Orsay (March 29, 2013); LIRMM, Montpellier (April 16, 2013);

D. Coudert: Visit to Univ. Adolfo Ibañez (part of EA AlDyNet), Santiago Chile (November 15-30, 2013);

F. Havet: Visit to LIRMM, Univ. Montpellier 2, (December 9-11, 2013);

A. Kodjo: Visit to Concordia Univ., Montreal, Canada, (August 1st-September 1st, 2013);

F.Z. Moataz and B. Li: Visit to Univ. Adolfo Ibañez, Santiago, Chile, (November 14-December 12, 2013);

N. Nisse: Visit to Univ. Adolfo Ibañez (part of EA AlDyNet), Santiago Chile (November 15-December 1st, 2013); Visit to Univ. Perugia, Italy (October 20-25, 2013)

9. Dissemination

9.1. Scientific Animation

9.1.1. Participation in Committees

J-C. Bermond: Expert for DRTT, and various projects outside France (Canada, Italy,...); Member of the Ph.D. committee of the University of Marseille;

D. Coudert: Member of the *comité du suivi doctoral* of Inria Sophia Antipolis (since January 2009); Member of the scientific board of the GIS ENSL-UNS (CNRS, ENSL, Inria, UNS) since 2011; Expert for the Future and Emerging Technologies Open Scheme (FET-Open) European program, and the ANR;

F. Giroire: Member of the *conseil de laboratoire I3S*;

F. Havet: Responsible of the Pôle ComRed of I3S (since September 2013); Expert for the ANR and its Czech analogues; Member of the *conseil de l'Ecole Doctorale I2S* (Montpellier);

M. Syska: Member of the commission ad-hoc ATER 27 UNS; Member of *Comité Permanent de Ressources Humaines* (CPRH) UNS 27e; Member of the *conseil de département* (Department Committee) of IUT Nice; Expert for DRTT PACA.

9.1.2. Editorial Boards

J-C. Bermond: Combinatorics Probability and Computing, Computer Science Reviews, Discrete Mathematics, Discrete Applied Mathematics, Journal of Graph Theory, Journal of Interconnection Networks (Advisory Board), Mathématiques et Sciences Humaines, Networks, Parallel Processing Letters, SIAM book series on Discrete Mathematics, Transactions on Network Optimization and Control, Discrete Mathematics, Algorithms and Applications;

D. Coudert: Discrete Applied Mathematics (Elsevier); Networks (Wiley);

F. Havet: Discrete Mathematics and Theoretical Computer Science;

9.1.3. Steering Committees

D. Coudert: Pôle ResCom du GDR ASR du CNRS (since 2005); Rencontres francophones sur les aspects algorithmiques des télécommunications (AlgoTel);

F. Havet: GT Graphes du GDR IM du CNRS; Journée Combinatoire et Algorithmes du Littoral Méditerranéen;

9.1.4. Conference Organization

ALGO'13: this scientific event comprises the *European Symposium on Algorithms* (ESA), the *Workshop on Algorithms for Bioinformatics* (WABI), the *International Symposium on Parameterized and Exact Computation* (IPEC), the *Workshop on Approximation and Online Algorithms* (WAOA), the *International Symposium on Algorithms for Sensor Systems, Wireless Ad Hoc Networks and Autonomous Mobile Entities* (ALGOSENSORS), the *Workshop on Algorithmic Approaches for Transportation Modeling, Optimization, and Systems* (ATMOS), and the *Workshop on Massive Data Algorithmics* (MASSIVE). Sophia Antipolis, France (September 2-6, 2013); D. Coudert and J. Moulierac were members of the organizing committee.

OPODIS'13: 17th International Conference On Principle Of DIstributed Systems; Conference Chair: N. Nisse; Organization Committee: A. Kodjo, B. Li.

9.1.5. Participation in Program Committees

D. Coudert: IEEE ICC – Green Communications and Networks Track, Budapest, Hungary (June 9-13, 2013); IEEE GLOBECOM – Green Networks and Communication Systems Track, Atlanta, GA, USA (December 9-13, 2013); 17th International Conference on Optical Network Design and Modeling (ONDM'13), Brest, France (April 16-19, 2013);

F. Havet: 15emes Journées Graphes et Algorithmes, Orsay, France (November 13-15, 2013);

N. Nisse: PC Chair of the 15th Rencontres francophones sur les aspects algorithmiques des télécommunications (AlgoTel) (May 28-31, 2013);

9.2. Participation in Conferences and Workshops

9.2.1. Invited Talks

J-C. Bermond: DIMACS Workshop on Algorithms for Green Data Storage, DIMACS, Rutgers University USA (December 18, 2013);

D. Coudert: Bell labs - NIST Workshop on Large-Scale Networks, Murray Hill, NJ, USA (October 25, 2013); AlDyNet Workshop on Algorithms and Randomness, Santiago , Chile (November 21, 2013);

F. Havet: School on Graph Theory, Oléron, France (June 17-21, 2010), five hour lecture on "Orientations and colorings of graphs";

N. Nisse: AlDyNet Workshop on Algorithms and Randomness, Santiago , Chile (November 21, 2013);

9.2.2. Participation in Scientific Meetings

ADR Network Science: Meeting of ADR Network Science of the Alcatel-Lucent / Inria Joint lab, Paris, France (February 28, 2013) Attended by D. Coudert (speaker) and N. Nisse (speaker); Sophia-Antipolis, France (December 5) Attended by D. Coudert;

COMRED: Journée du pôle COMRED (December 3-4, 2013). Attended by all members of COATI;

DIMAGREEN: Journées de l'ANR - Rencontres du numérique (April 17-18, 2013). Attended by F. Giroire;

EULER: Plenary meeting of FP7 STREP EULER , Antwerp, Belgium (September 23-25, 2013). Attended by D. Coudert and A. Lancin.

GDL: GreenDay@Lille, Lille, France (November 28-29, 2013). Attended by K. Phan;

JFRO: 29e Journee Francilienne de Recherche Operationnelle, Paris, France (June 4, 2013). Attended by J. Araújo, B. Li, N. Nisse;

JGA: 15èmes Journées Graphes et Algorithmes, Orsay, France (November 13-15, 2013). Attended by J. Araújo, F. Havet, A. Maia (speaker);

JIF: Journées D'informatique fondamentale de Paris Diderot (April 24, 2013). Attended by N. Nisse;

Journées REP: Journées Scientifiques and Journée REP of Inria, Rennes, France (June 25-27, 2013). Attended by D. Coudert;

Inria- Alcatel Lucent Bell Labs: Kick off meeting Phase 2 of the Common Lab Inria-Alcatel Lucent Bell Labs, Nozay, France (March 27, 2013). Attended by J-C. Bermond;

POC: Polyèdres et Optimisation Combinatoire: Journée sur l'Optimisation Robuste et la programmation mathématique Paris, France (December 6th, 2013). Attended by A. Kodjo;

SEAT: meeting for preparing submission of ANR SEAT (October 2nd, 2013). Attended by D. Coudert and N. Nisse;

Struco: Meeting on Combinatorics and Distributed Computing, Pont-à-Mousson, (November 12-15, 2013). Attended by F. Havet;

TREND: NoE TREND Plenary Meeting, Catania, Italy (February 6-8, 2013). Attended by F. Giroire;

9.2.3. Participation in Conferences

AlDyNet: AlDyNet Workshop on Algorithms and Randomness, Santiago, Chile (November 21, 2013). Attended by D. Coudert (speaker), B. Li (speaker), F. Moataz (speaker), N. Nisse (speaker);

ALGO: Sophia Antipolis, France (September 2-6, 2013). Attended by all members of COATI;

Algotel: 15èmes Rencontres Francophones pour les Aspects Algorithmiques des Telecommunications, Pornic, France (May 28-31, 2013). Attended by F. Moataz (speaker), N. Nisse, D. Coudert, G. Ducoffe (speaker), I. Tahiri, A. Lancin, R. Soares (speaker) and F. Giroire;

DIMACS: Working group and Workshop on Algorithms for Green Data Storage, DIMACS, Rutgers University USA (December 16-18, 2013). Attended by J-C. Bermond (speaker);

DRCN: the 9th International Conference on Design of Reliable Communication Networks, Budapest, Hungary (March 4-7, 2013). Attended by F.Z. Moataz (speaker);

EURO: 26th European Conference on Operational Research, Roma, Italy (July 2-4, 2013). Attended by C. Molle-Caillouet (speaker), D. Coudert and N. Nisse (speaker);

GIIS: Global Information Infrastructure and Networking Symposium, Trento, Italy (October 28-31, 2013). Attended by A. Kodjo (speaker);

Globe: 6th International Conference on Data Management in Cloud, Grid and P2P Systems, Prague, Czech Republic (August 28-29, 2013). Attended by R. Modrzejewski (speaker);

Globecom: IEEE Global Communications Conference, Atlanta, United States (December 9-13, 2013). Attended by F. Giroire (speaker);

GROW: 6th workshop on Graph Classes, Optimization, and Width Parameters, Santorini Island (October 09–11, 2013). Attended by F. Havet (speaker) and N. Nisse;

ICC: IEEE International Conference on Communications, Budapest, Hungary (June 912, 2013). Attended by R. Modrzejewski (speaker);

ICGCC: IEEE International Conference on Green Computing and Communications, Beijing, China (August 20-23, 2013). Attended by K. Phan (speaker);

INOC: 6th International Network Optimization Conference, Tenerife, Spain (May 20-22, 2013). Attended by I. Tahiri (speaker);

LAGOS: VII Latin-American Algorithms, Graphs and Optimization Symposium, Playa del Carmen, Mexico (April 22-26, 2013). Attended by J. Araújo (speaker), A. Maia (speaker), P. Moura (speaker), R. Soares (speaker);

OPODIS: 17th International Conference On Principle Of DIstributed Systems, Nice, France (December 16-18, 2013). Attended by B. Li, A. Kodjo and N. Nisse

SIROCCO: 20th International Colloquium on Structural Information and Communication Complexity, Ischia, Italy (July 1–3, 2013). Attended by F. Giroire (speaker) and N. Nisse (speaker);

WLSN: Bell labs - NIST Workshop on Large-Scale Networks, Murray Hill, NJ, USA (October 25, 2013). Attended by D. Coudert;

9.2.4. Participation in Schools

CSP: School on Constraint Satisfaction problems, ENS Lyon, France (January 21-25, 2013). Attended by F. Moataz;

EULERSS: Summer School on Graph and Routing Dynamics: Models and Algorithms, Barcelona, Spain (July 1-5, 2013). Attended by F. Moataz, B. Li and A. Lancin;

JCALM13: 13es Journées Combinatoire et Algorithmes du Littoral Méditerranéen, Marseille, France (June 10-11, 2013). Attended by J. Araújo, G. Ducoffe, F. Giroire, A. Maia, N. Nisse;

JCALM14: 14es Journées Combinatoire et Algorithmes du Littoral Méditerranéen, Barcelona, Spain (October 14-15, 2013). Attended by F. Havet (speaker), A. Maia

NetOpt: Winter School on Network Optimization, Estoril, Portugal (January 14-18, 2013). Attended by B. Li and A. Kodjo;

ResCom: Summer school ResCom 2013 of GDR ASR of CNRS on Content Centric Networks, Porquerolles, France (May 13-17, 2013). Attended by J-C. Bermond, D. Coudert, F. Giroire, R. Modrzejewski;

SGT: Summer School on Graph Theory, île d'Oléron, France (June 17-21, 2013). Attended by J. Araújo, F. Havet, B. Li, A. Maia, F. Moataz, N. Nisse;

TREND: The TREND PhD School in Green Networking, Turin, Italy (July 1-5, 2013). Attended by K. Phan;

9.3. Teaching - Supervision - Juries

9.3.1. Teaching

Licence: A. Kodjo, Algorithme-Programmation Objet-Python, 40h ETD, L2, Networks, 15h ETD, L2, IUT Nice Côte d'Azur, Informatique pratique, 36h ETD, L1,Univ. Nice Sophia Antipolis;

Licence: F. Moataz, Systèmes Informatiques, 40h ETD, L1, Univ. Nice Sophia Antipolis;

Licence: C. Molle-Caillouet, IT Tools, 53h, L1, Database and advanced information system, 36h, L2, Operations Research, 81h, L2, Delivery Optimization, 30h, L3, IUT Nice Côte d'Azur, Univ. Nice Sophia Antipolis;

Licence: J. Moulierac, Algorithms and Programming, 100h ETD, L1, ASR5 - Networks, 30h ETD, L1, IUT Nice Côte d'Azur, Univ. Nice Sophia Antipolis;

Licence: N. Nisse, informatique, 30h ETD, 1ère année classes préparatoires (L1), CIV, Sophia Antipolis, France;

Licence: I. Tahiri, Introduction to networks, 96h ETD, L1, IUT Nice Côte d'Azur, Univ. Nice Sophia Antipolis;

Licence: M. Syska, Introduction to Operating Systems, 40h ETD, L1, Operating Systems : Advanced Programming, 60h ETD, L2, Bash Scripting, 20h ETD, L3, Introduction to Algorithms, 30h ETD, L3, Linux Systems Administration, 40h ETD, L3, IUT Nice Côte d'Azur, Univ. Nice Sophia Antipolis.

Master: D. Coudert, Algorithms for Telecommunication 2, 30 ETD, M2 Ubinet of Master IFI, Univ. Nice Sophia Antipolis;

Master: F. Giroire, 16h ETD, Introduction to Probabilities and Statistics, International track of the Master 1 IFI, Univ. Nice Sophia Antipolis;

Master: F. Giroire and N. Nisse, Algorithms for Telecommunications, 30h ETD, M2 Ubinet of Master IFI, Univ. Nice Sophia Antipolis;

Master: F. Giroire and N. Nisse, Algorithms for Telecommunications, 36h ETD, M2, Master MDFI, Univ. Marseille;

Master: F. Havet, Discharging Method, 6h, M2, Simon Fraser University, Canada.

Master: A. Kodjo, Réseaux, 15h ETD, M1, Univ. Nice Sophia Antipolis;

9.3.1.1. Administration

Collaboration Inria-Lycée International de Valbonne: N. Nisse is co-responsible of the Computer Science course of MPSI;

IUT Nice Côte d'Azur: J. Moulierac is Directrice d'études of Semestre 2 décalé at IUT Nice Côte d'Azur, Computer Science Department since september 2013;
M. Syska is responsible of the Computer Science Department of IUT since september 2011;

Ubinet, Master IFI: J.-C. Bermond is member of the scientific committee;
F. Giroire is responsible of the Internships within international stream Ubinet, Master IFI (http://ubinet.unice.fr), since October 2011;

International Master 1: J.-C. Bermond is member of the scientific committee of the international track of the M1 (http://computerscience.unice.fr/master1).

9.3.2. Supervision

PhD:

R. Modrzejewski, *Systèmes pair-à-pair de partage de données*, October 24, 2013, S. Pérennes and F. Giroire.

R. Pardo Soares, *Routing reconfiguration in WDM networks*, November 8, 2013, D. Coudert, C. Linhares Sales and N. Nisse.

PhD in progress:

I. Tahiri, *Optimisation dans les réseaux de collecte IP sans fils*, since November 2009, D. Coudert.

4th year:

S. Félix, *Smart transports : optimisation du trafic dans les villes*, since January 2011, J.-C. Bermond and J. Galtier.

A. Lancin, *Study of network properties for efficient routing algorithms*, since January 2011, D. Coudert.

3rd year:

M. A. Bergach, *GPGPU Graphics Processing Units for signal processing*, since September 2011, M. Syska.

A. Kodjo, *Design and optimization of multi-operators wireless backhaul networks*, since October 2011, D. Coudert.

B. Li, *Tree-decomposition and applications to routing*, since October 2011, D. Coudert and N. Nisse.

A. K. Maia, *Partitions of directed graphs*, since September 2011, F. Havet.

T. K. Phan, *Design and Management of networks with low-power Consumption*, since October 2011, D. Coudert and J. Moulierac.

2nd year:

F. Z. Moataz, *Conception et optimisation de réseaux robustes aux pannes et variations de capacités*, since October 2012, D. Coudert.

9.3.2.1. Internships

D. Coudert: supervised the internship of Guillaume Ducoffe (ENS Cachan, Paris, France) on "Computation in Large Graphs with Applications to Gromov Hyperbolicity", March-September 2013 (6 months);

F. Havet: supervised the internship of Mathieu Schmitt (École Normale Supérieure de Lyon, France) on backbone colouring, May-August 2013 (3 months).

N. Nisse: supervised the internship of Christos Papageorgakis (University of Thessaly, Volos, Greece) on implementation of Cops and Robber games, February-July 2013 (6 months);

N. Nisse and S. Pérennes: supervised the internship of Ioannis Lamprou (University of Athens, Greece) on fractional games in graphs, March-August 2013 (6 months);

9.3.3. Juries

J-C. Bermond: member of the PhD jury of Remigiusz Modrzejewski, Univ. Nice Sophia Antipolis (October 24, 2013);

D. Coudert: Member of the PhD jury of Valentin Weber, Université de Grenoble, France (July 8, 2013); Referee and member of the PhD jury of Jiyai Liu, Télécom Bretagne, Rennes, France (November 4, 2013); Member of the PhD jury of Ronan Soares, Univ. Nice Sophia Antipolis, France (November 8, 2013); Member of the PhD jury of Christian Glacet, Université de Bordeaux 1, Bordeaux, France (December 6, 2013);

F. Giroire: member of the PhD jury of Ngo Hoang Giang, Univ. Nice Sophia Antipolis (December 16, 2013); member of the PhD jury of Remigiusz Modrzejewski, Univ. Nice Sophia Antipolis (October 24, 2013);

F. Havet: external referee of the PhD of S. Simonsen, University of Southern Denmark (November 7 2013); external referee of the PhD of A. Maddaloni, University of Southern Denmark (November 8 2013);

N. Nisse: member of the PhD jury of Ronan Soares, Univ. Nice Sophia Antipolis (November 8, 2013);

9.4. Popularization

Attractiveness: J-C. Bermond is in charge of the attractiveness of the center Inria Sophia Antipolis Méditerannée. Among other activities he corganized The "Mediterranean days" (January 23-25) (25 foreign students invited) and co-organized the valorization afternoon on February 2, 2013 (100 students);

Fête de la Science: F. Giroire presented the stand "Magie et jeux mathématiques" at the Centre International de Valbonne, France (October 8, 2013); F. Moataz assisted the stand "Drone/Unmanned Aerial Vehicle" at Sophia Antipolis, France (October 12-13, 2013);

Formation EDSTIC: J. Aráujo has given lectures on Graph Theory and Algorithms to PhD students, 20h;

Mathématiques et Internet: J-C. Bermond gave a vulgarization talk at the Centre Culturel of La Grande Motte, Hérault France (April 16, 2013);

Optimisation dans les réseaux: J-C. Bermond gave 3 talks to investors on the future of optimization in networks, Paris (March 28, 2013);

Science culture au lycée, Inria/PACA: N. Nisse explains graph to a Lycée class at Marseille, France (December 19th, 2013);

10. Bibliography

Major publications by the team in recent years

[1] D. AGARWAL, J. ARAUJO, C. CAILLOUET, F. CAZALS, D. COUDERT, S. PERENNES. *Connectivity Inference in Mass Spectrometry based Structure Determination*, in "European Symposium on Algorithms", Sophia-Antipolis, France, France, H. BODLAENDER, G. ITALIANO (editors), Lecture Notes in Computer Science - LNCS, Springer, 2013, vol. 8125, pp. 289-300 [*DOI :* 10.1007/978-3-642-40450-4_25], http://hal.inria.fr/hal-00849873

[2] E. ALTMAN, P. NAIN, J.-C. BERMOND. *Distributed Storage Management of Evolving Files in Delay Tolerant Ad Hoc Networks*, in "INFOCOM 2009", Rio De Janeiro, Brazil, April 2009, pp. 1431 - 1439, http://dx.doi.org/10.1109/INFCOM.2009.5062059

[3] J.-C. BERMOND, D. COUDERT, J. MOULIERAC, S. PÉRENNES, I. SAU, F. SOLANO DONADO. *GMPLS Label Space Minimization through Hypergraph Layouts*, in "Theoretical Computer Science", July 2012, vol. 444, pp. 3-16, http://hal.inria.fr/hal-00706260

[4] J.-C. BERMOND, F. ERGINCAN, M. SYSKA. *Line Directed Hypergraphs*, in "Quisquater Festschrift", D. NACCACHE (editor), Lecture Notes in Computer Science, Springer-VerlagBerlin Heidelberg, 2011, vol. 6805, pp. 25-34, http://hal.archives-ouvertes.fr/hal-00643785

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[7] N. COHEN, D. COUDERT, D. MAZAURIC, N. NEPOMUCENO, N. NISSE. *Tradeoffs in process strategy games with application in the WDM reconfiguration problem*, in "Theoretical Computer Science (TCS)", August 2011, vol. 412, n^o 35, pp. 4675-4687, http://dx.doi.org/10.1016/j.tcs.2011.05.002

[8] F. V. FOMIN, P. FRAIGNIAUD, N. NISSE. *Nondeterministic Graph Searching: From Pathwidth to Treewidth*, in "Algorithmica", 2009, vol. 53, n^o 3, pp. 358-373, http://www.springerlink.com/content/42g5tp1588w89186/

[9] F. GIROIRE. *Order statistics and estimating cardinalities of massive data sets*, in "Discrete Applied Mathematics", 2009, vol. 157, n^o 2, pp. 406-427, http://dx.doi.org/10.1016/j.dam.2008.06.020

[10] F. GIROIRE, D. MAZAURIC, J. MOULIERAC. *Energy Efficient Routing by Switching-Off Network Interfaces*, in "Energy-Aware Systems and Networking for Sustainable Initiatives", N. KAABOUCH, W.-C. HU (editors), IGI Global, 2012, pp. 207-236, http://hal.inria.fr/hal-00759894

[11] S. GUILLEMOT, F. HAVET, C. PAUL, A. PEREZ. *On the (non-)existence of polynomial kernels for P_l-free edge modification problems*, in "Algorithmica", 2013, vol. 65, n^o 4, pp. 900-926, http://hal.inria.fr/hal-00821612

[12] F. HAVET, B. REED, J.-S. SERENI. *Griggs and Yeh's Conjecture and L(p,1)-labelings*, in "Siam Journal on Discrete Mathematics", February 2012, vol. 26, n^o 1, pp. 145–168, http://hal.inria.fr/inria-00327909

Publications of the year

Doctoral Dissertations and Habilitation Theses

[13] R. MODRZEJEWSKI. , *Distribution et stockage dans les réseaux*, Université Nice Sophia Antipolis, October 2013, http://hal.inria.fr/tel-00917032

[14] R. PARDO SOARES. , *Jeux de poursuite-évasion, décompositions et convexité dans les graphes*, Université Nice Sophia Antipolis and Universidade federal do Ceará, November 2013, http://hal.inria.fr/tel-00908227

Articles in International Peer-Reviewed Journals

[15] L. ADDARIO-BERRY, F. HAVET, C. LINHARES SALES, B. REED, S. THOMASSÉ. *Oriented trees in digraphs*, in "Discrete Mathematics", 2013, vol. 313, n^o 8, pp. 967-974 [*DOI :* 10.1016/J.DISC.2013.01.011], http://hal.inria.fr/hal-00821609

[16] J. ARAUJO, V. CAMPOS, F. GIROIRE, N. NISSE, L. SAMPAIO, R. SOARES. *On the hull number of some graph classes*, in "Theoretical Computer Science", January 2013, vol. 475, pp. 1-12 [*DOI :* 10.1016/J.TCS.2012.12.035], http://hal.inria.fr/hal-00770650

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[21] S. BESSY, F. HAVET. *Enumerating the edge-colourings and total colourings of a regular graph*, in "Journal of Combinatorial Optimization", 2013, vol. 25, n^o 4, pp. 523-535 [*DOI :* 10.1007/S10878-011-9448-5], http://hal.inria.fr/hal-00821598

[22] V. CAMPOS, F. HAVET, R. SAMPAIO, A. SILVA. *Backbone colouring: Tree backbones with small diameter in planar graphs*, in "Theoretical Computer Science", 2013, vol. 487, pp. 50-64 [*DOI :* 10.1016/J.TCS.2013.03.003], http://hal.inria.fr/hal-00821608

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International Conferences with Proceedings

[28] D. AGARWAL, J. ARAUJO, C. CAILLOUET, F. CAZALS, D. COUDERT, S. PERENNES. *Connectivity Inference in Mass Spectrometry based Structure Determination*, in "European Symposium on Algorithms", Sophia-Antipolis, France, France, H. BODLAENDER, G. ITALIANO (editors), Lecture Notes in Computer Science - LNCS, Springer, 2013, vol. 8125, pp. 289-300 [*DOI :* 10.1007/978-3-642-40450-4_25], http://hal.inria.fr/hal-00849873

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[30] J. ARAUJO, G. MOREL, L. SAMPAIO, R. SOARES, V. WEBER. *Hull number: P5-free graphs and reduction rules*, in "VII Latin-American Algorithms, Graphs and Optimization Symposium (LAGOS)", Playa del Carmen, Mexico, March 2013, http://hal.inria.fr/hal-00799868

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