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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

Creation of the Project-Team: 2013 January 01.

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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 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 Sage.

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 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 SME like 3-Roam.

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). We have also started a collaboration with Amadeus on complex journey planning.

5. New Software and Platforms

5.1. JourneyPlanner

Participant: Marco Biazzini [correspondant].

JourneyPlanner is a Java implementation of a recursive algorithm to solve a TSP problem on small dense graphs, where non-trivial constraints must be satisfied, that make commonly used paradigms (as dynamic programming) unfit to the task.

This work is done in collaboration with the R&D service of the "Train Transportation" division of Amadeus.

5.2. Software updates

Participants: David Coudert, Luc Hogie, Aurélien Lancin, Nicolas Nisse, Michel Syska.

During this year, we have maintained and augmented already existing softwares. In particular:

- DRMSim (http://drmsim.gforge.inria.fr/) : discrete-event simulation engine aiming at enabling the large-scale simulations of routing models.
- GRPH (http://grph.inria.fr) : graph optimization library written in Java. This year, we have integrated the discrete-events simulation engine of DRMSim and some dynamic models (evolution of the connectivity with the mobility of nodes) to GRPH. Notice that we have identified more than 300 academic users of GRPH.
- Sage (http://www.sagemath.org) : open-source mathematics software initially created by William Stein (Professor of mathematics at Washington University). We contribute the addition of new graph algorithms along with their documentations and the improvement of underlying data structures.

5.3. Platforms

5.3.1. BigGraphs

Participants: Aurélien Lancin, Paul Bertot, Nicolas Chleq [SED-SOP], David Coudert, Luc Hogie, Fabrice Huet [Scale], Flavian Jacquot, Arnaud Legout [Diana], Eric Madelaine [Scale], Michel Syska [coordinator].

The objective of BigGraphs is to provide a distributed middleware for very large graphs processing. This new project has received a development grant (ADT) from Inria and is a joint work of three EPI from Inria: COATI, DIANA and SCALE.

The first phase of the project consists in the evaluation of the existing middlewares such as GraphX/Spark or Giraph/Hadoop with respect to the following criteria: ease of deployment, maintenance and use; variety of programming models (Map/Reduce, BSP, (a)synchronous message passing, centralized programming, mobile agent-based, etc.); overall efficiency and memory footprint; etc. One of the chosen use cases is a subgraph of the Twitter graph with 3 millions of nodes and 200 millions of edges. The experiments are run on the NEF cluster at Inria. We have implemented and tested the classic algorithms (using the BSP model): page rank, BFS, connected components as well as the iFUB algorithm for computing the diameter of large graphs.

In parallel, we are testing new ideas through the development of custom solutions for the deployment of application code in heterogeneous environments, for automatic discovery of cluster architecture, for the design of distributed object oriented applications, and techniques for distributed graph computing (asynchronous BSP, messaging, multi-core parallelism, etc.).

The next phase is to decide whether one framework is matching our needs (and use it as a basis for further developments) or if we have to produce our own.

6. New Results

6.1. Network Design and Management

Participants: Jean-Claude Bermond, David Coudert, Frédéric Giroire, Frédéric Havet, Alvinice Kodjo, Aurélien Lancin, Bi Li, Fatima Zahra Moataz, Christelle Molle-Caillouet, Joanna Moulierac, Nicolas Nisse, Stéphane Pérennes, Truong Khoa Phan.

More information on several results presented in this section may be found in the PhD thesis of A. Kodjo [13], B. Li [15] and T. K. Phan [18].

6.1.1. Optimization in backbone networks

6.1.1.1. Shared Risk Link Group

The notion of Shared Risk Link Groups (SRLG) captures survivability issues when a set of links of a network may fail simultaneously. The theory of survivable network design relies on basic combinatorial objects that are rather easy to compute in the classical graph models: shortest paths, minimum cuts, or pairs of disjoint paths. In the SRLG context, the optimization criterion for these objects is no longer the number of edges they use, but the number of SRLGs involved. Unfortunately, computing these combinatorial objects is NP-hard and hard to approximate with this objective in general. Nevertheless some objects can be computed in polynomial time when the SRLGs satisfy certain structural properties of locality which correspond to practical ones, namely the star property (all links affected by a given SRLG are incident to a unique node) and the span 1 property (the links affected by a given SRLG form a connected component of the network). The star property is defined in a multi-colored model where a link can be affected by several SRLGs while the span property is defined only in a mono-colored model where a link can be affected by at most one SRLG. In [52], we extend these notions to characterize new cases in which these optimization problems can be solved in polynomial time or are fixed parameter tractable. We also investigate on the computational impact of the transformation from the multi-colored model to the mono-colored one. Experimental results are presented to validate the proposed algorithms and principles.

6.1.1.2. Dynamic Routing and Spectrum Assignment in Optical Networks

Elastic Optical Networks (EONs) promises a better utilization of the spectrum in optical networks. In fact, as the optical transmission spectrum is carved into fixed-length bands in the traditional WDM networks, small bit rates are over-provisioned and very high bit rates do not fit. EONs are moving away from this fixed-grid and allow the spectrum to be divided flexibly: each request is allocated exactly the resources it needs. In [34], we present two exact algorithms to route and allocate spectrum to a new request in an EON using only Non-Disruptive Defragmentation (Push-Pull). In the first algorithm, we find the shortest routing path for the new request (i.e., the shortest path from source to destination where contiguous spectrum to satisfy the request can be freed) and then find the position that gives the overall minimum delay on that path. In the second algorithm, we find at the same time a routing path and a position in the spectrum, that minimize the delay of insertion (over all other paths and positions). Both algorithms are polynomial in the size of the network, its bandwidth and the number of provisioned requests.

6.1.2. Microwave Backhaul networks

6.1.2.1. Chance-Constrained Optimization of Reliable Backhaul networks

In [25], we extend our former investigation on conceiving reliable fixed point-to-point wireless networks under outage probability constraints. We consider the problem of determining the minimum cost bandwidth assignment of a network, while guaranteeing a reliability level of the solution. If the optimal bandwidth assignment and routing of traffic demands are accomplished, the reliability criterion requires that network flows remain feasible with high probability, regarding that the performance of microwave links is prone to variations due to external factors, e.g., weather. We introduce a *chance-constrained programming* approach to tackle this problem and we present reformulations to standard integer linear programming models, including a budget-constrained formulation. To improve the solving performance, we propose new valid inequalities and a primal heuristic. Computational results present a performance analysis of the valid inequalities and the heuristic. Further, the outperformance of the novel model compared to more traditional approaches is documented.

6.1.2.2. Robust optimization in multi-operators microwave backhaul networks

In [41], 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.

6.1.3. Energy efficiency

6.1.3.1. Robust Optimization for Energy-aware Routing with Redundancy Elimination

Many studies in literature have shown that energy-aware routing (EAR) can significantly reduce energy consumption for backbone networks. Also, as an arising concern in networking research area, the protocol-independent traffic redundancy elimination (RE) technique helps to reduce (a.k.a compress) traffic load on backbone network. In [35], [50], we present an extended model of the classical multi-commodity flow problem with compressible flows. Our model is robust with fluctuation of traffic demand and compression rate. In details, we allow any set of a predefined size of traffic flows to deviate simultaneously from their nominal volumes or compression rates. As an applicable example, we use this model to combine redundancy elimination and energy-aware routing to increase energy efficiency for a backbone network. Using this extra knowledge on the dynamics of the traffic pattern, we are able to significantly increase energy efficiency for the network. We formally define the problem and model it as a Mixed Integer Linear Program (MILP). We then propose an efficient heuristic algorithm that is suitable for large networks. Simulation results with real traffic traces on Abilene, Geant and Germany50 networks show that our approach allows for 16-28% extra energy savings with respect to the classical EAR model.

6.1.3.2. Optimizing IGP Link Weights for Energy-efficiency in a Changing World

Recently, due to the increasing power consumption and worldwide gas emissions in ICT (Information and Communication Technology), energy efficient ways to design and operate backbone networks are becoming a new concern for network operators. Since these networks are usually overprovisioned and since traffic load has a small influence on power consumption of network equipments, the most common approach to save energy is to put unused line cards that drive links between neighbouring routers into sleep mode. To guarantee QoS, all traffic demands should be routed without violating capacity constraints and the network should keep its connectivity. From the perspective of traffic engineering, we argue that stability in routing configuration also plays an important role in QoS. In details, frequent changes in network configuration (link weights, slept and activated links) to adapt with traffic fluctuation in daily time cause network oscillations. We propose in [62] a novel optimization method to adjust the link weights of Open Shortest Path First (OSPF) protocol while limiting the changes in network configurations when multi-period traffic matrices are considered. We formally define the problem and model it as Mixed Integer Linear Program (MILP). We then propose an efficient heuristic algorithm that is suitable for large networks. Simulation results with real traffic traces on three different networks show that our approach achieves high energy saving while keeping the networks in stable state (less changes in network configuration).

6.1.3.3. Grid spanners with low forwarding index for energy efficient networks

A routing R of a connected graph G is a collection that contains simple paths connecting every ordered pair of vertices in G. The edge-forwarding index with respect to R (or simply the forwarding index with respect to R) $\pi(G,R)$ of G is the maximum number of paths in R passing through any edge of G. The forwarding index $\pi(G)$ of G is the minimum $\pi(G,R)$ over all routings R's of G. This parameter has been studied for different graph classes. Motivated by energy efficiency, we look in [57], for different numbers of edges, at the best spanning graphs of a square grid, namely those with a low forwarding index.

6.1.4. Software-Defined Networks

6.1.4.1. Rule Placement in Software-Defined Networks for Energy-aware Routing

Software-defined Networks (SDN), in particular OpenFlow, is a new networking paradigm enabling innovation through network programmability. Over past few years, many applications have been built using SDN such as server load balancing, virtual-machine migration, traffic engineering and access control. We focus on using SDN for energy-aware routing (EAR). SDN can collect traffic matrix and then computes routing solutions satisfying QoS while being minimal in energy consumption (with minimal number of active links). However, prior works on EAR have assumed that the table of OpenFlow switch can hold an infinite number of rules. In practice, this assumption does not hold since the flow table is implemented with Ternary Content Addressable Memory (TCAM) which is expensive and power-hungry. In [39], [56], we propose an optimization method to minimize energy consumption for a backbone network while respecting capacity constraints on links and rule space constraints on routers. In details, we present an exact formulation using Integer Linear Program (ILP) and introduce efficient greedy heuristic algorithm. Based on simulations, we show that using this smart rule space allocation, it is possible to save almost as much power consumption as the classical EAR approach.

6.1.4.2. Compressing Two-dimensional Routing Tables with Order

A communication in a network is a pair of nodes (s,t). The node s is called the source source and t the destination. A communication set is a set of distinct communications, i.e. two communications might have the same source or the same destination, but they cannot have both same source and same destination. A routing of a communication (s,t) is a path in the network from s to t. A routing of a communication set is a union of routings of its communications. At each node, there is a set X of communications whose routing path goes through this node. The node needs to be able to find for each communication (s,t) in X, the port that the routing path of (s,t) uses to leave it. An easy way of doing it is to store the list of all triples (s,t,k), where $(s,t) \in X$ and k is the port used by the (s,t)-path to leave the node. Such triples are called communication triples. However, such a list might be very large. Motivated by routing in telecommunication network using Software Defined Network Technologies, we consider in [55] the problem of compacting this list using aggregation rules. Indeed, SDN routers use specific memory which is expensive and of small capacity. Hence, in addition, we can use some additional triples, called *-triples. As an example, a t-destination triple $(*,t,p)$, means that every communication with destination t leaves on port p. We carry out in this work a study of the problem complexity, providing results of NP-completeness, of Fixed-Parameter Tractability and approximation algorithms.

6.1.5. Data gathering in radio networks

In the gathering problem, a particular node in a graph, the base station, aims at receiving messages from some nodes in the graph. At each step, a node can send one message to one of its neighbors (such an action is called a call). However, a node cannot send and receive a message during the same step. Moreover, the communication is subject to interference constraints ; more precisely we consider a binary interference model where two calls interfere in a step, if the sender of one call is at distance at most d_I from the receiver of the other call. Given a graph with a base station and a set of nodes having some messages, the goal of the gathering problem is to compute a schedule of calls for the base station to receive all messages as fast as possible, i.e., minimizing the number of steps (called makespan). The gathering problem is equivalent to the personalized broadcasting problem where the base station has to send messages to some nodes in the graph, with same transmission constraints. In [23], we focus on the gathering and personalized broadcasting problem in grids. Moreover, we consider the non-buffering model: when a node receives a message at some step, it must transmit it during the next step. 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 $d_I \in \{0, 1, 2\}$. In particular, we present an algorithm that achieves the optimal makespan up to an additive constant 2 when $d_I = 0$. If no messages are "close" to the axes (the base station being the origin), our algorithms achieve the optimal makespan up to an additive constant 1 when $d_I = 0$, 4 when $d_I = 2$, and 3 when both $d_I = 1$ and the base station is in a corner. 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.

6.2. Graph Algorithms

Participants: Julio Araújo, Jean-Claude Bermond, David Coudert, Guillaume Ducoffe, Frédéric Giroire, Aurélien Lancin, Bi Li, Fatima Zahra Moataz, Christelle Molle-Caillouet, Nicolas Nisse, 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 PhD thesis of B. Li [15] and A. Lancin [14], and in the Habilitation thesis of N. Nisse [17].

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. 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 [47], we investigate some relations between the hyperbolicity of a graph and the hyperbolicity of its *atoms*, that are the subgraphs resulting from the decomposition of the graph according its clique minimal separators. More precisely, we prove that the maximum hyperbolicity taken over all the atoms is at least the hyperbolicity of G *minus one*. We also give an algorithm to slightly modify the atoms, which is at no extra cost than computing the atoms themselves, and so that the maximum hyperbolicity taken over all the resulting graphs is *exactly* the hyperbolicity of G. An experimental evaluation of our methodology is provided for large collaboration networks. Finally, we deduce from our theoretical results the first *linear-time* algorithm to compute the hyperbolicity of an outerplanar graph.

The shortest-path metric d of a connected graph G is 1/2-hyperbolic if, and only if, it satisfies $\mathrm{d}(u,v) + \mathrm{d}(x,y) \leq \max\{\mathrm{d}(u,x) + \mathrm{d}(v,y), \mathrm{d}(u,y) + \mathrm{d}(v,x)\} + 1$, for every 4-tuple u, x, v, y of G. We show in [26], [48] that the problem of deciding whether an unweighted graph is 1/2-hyperbolic is subcubic equivalent to the problem of determining whether there is a chordless cycle of length 4 in a graph. An improved algorithm is also given for both problems, taking advantage of fast rectangular matrix multiplication. In the worst case it runs in $O(n^{3.26})$-time.

6.2.1.2. Branch and Bound Algorithm for computing Pathwidth

It is well known that many NP-hard problems are tractable in the class of bounded pathwidth graphs. In particular, path-decompositions of graphs are an important ingredient of dynamic programming algorithms for solving such problems. Therefore, computing the pathwidth and associated path-decomposition of graphs has both a theoretical and practical interest. In [36], [51], we design a Branch and Bound algorithm that computes the exact pathwidth of graphs and a corresponding path-decomposition. Our main contribution consists of several non-trivial techniques to reduce the size of the input graph (pre-processing) and to cut the exploration space during the search phase of the algorithm. We evaluate experimentally our algorithm by comparing it to existing algorithms of the literature. It appears from the simulations that our algorithm offers a significative gain with respect to previous work. In particular, it is able to compute the exact pathwidth of any graph with less than 60 nodes in a reasonable running-time (10 min.). Moreover, our algorithm also achieves good performance when used as a heuristic (i.e., when returning best result found within bounded time-limit). Our algorithm is not restricted to undirected graphs since it actually computes the vertex-separation of digraphs (which coincides with the pathwidth in case of undirected graphs).

6.2.1.3. To satisfy impatient Web surfers is hard

Prefetching is a basic mechanism for faster data access and efficient computing. An important issue in prefetching is the tradeoff between the amount of network's resources wasted by the prefetching and the gain of time. For instance, in the Web, browsers may download documents in advance while a Web surfer is surfing. Since the Web surfer follows the hyperlinks in an unpredictable way, the choice of the Web pages to be prefetched must be computed online. The question is then to determine the minimum amount of resources used by prefetching that ensures that all documents accessed by the Web surfer have previously been loaded in the cache. In [28], we model this problem as a two-player game similar to Cops and Robber Games in graphs. Let $k \geq 1$ be any integer. The first player, a fugitive, starts on a marked vertex of a (di)graph G. The second player, an observer, marks at most k vertices, then the fugitive moves along one edge/arc of G to a new vertex, then the observer marks at most k vertices, etc. The fugitive wins if it enters an unmarked vertex, and the observer wins otherwise. The surveillance number of a (di)graph is the minimum k such that the observer marking at most k vertices at each step can win against any strategy of the fugitive. We also consider the connected variant of this game, i.e., when a vertex can be marked only if it is adjacent to an already marked vertex. We study the computational complexity of the game. All our results hold for both variants, connected or unrestricted. We show that deciding whether the surveillance number of a chordal graph is at most 2 is NP-hard. We also prove that deciding if the surveillance number of a DAG is at most 4 is PSPACE-complete. Moreover, we show that the problem of computing the surveillance number is NP-hard in split graphs. On the other hand, we provide polynomial-time algorithms computing surveillance numbers of trees and interval graphs. Moreover, in the case of trees, we establish a combinatorial characterization of the surveillance number.

6.2.2. Tree-decompositions

6.2.2.1. Minimum Size Tree-Decompositions

Tree-Decompositions are the corner-stone of many dynamic programming algorithms for solving graph problems. Since the complexity of such algorithms generally depends exponentially on the width (size of the bags) of the decomposition, much work has been devoted to compute tree-decompositions with small width. However, practical algorithms computing tree-decompositions only exist for graphs with treewidth less than 4. In such graphs, the time-complexity of dynamic programming algorithms based on tree-decompositions is dominated by the size (number of bags) of the tree-decompositions. It is then interesting to try to minimize the size of the tree-decompositions. In [42], [60], we consider the problem of computing a tree-decomposition of a graph with width at most k and minimum size. More precisely, we focus on the following problem: given a fixed $k \geq 1$, what is the complexity of computing a tree-decomposition of width at most k with minimum size in the class of graphs with treewidth at most k? We prove that the problem is NP-complete in planar graphs for any fixed $k \geq 4$ and polynomial for $k \leq 2$. We also show that for $k = 3$ the problem can be solved in polynomial time in the class of trees and 2-connected outerplanar graphs.

6.2.2.2. Exclusive Graph Searching vs. Pathwidth

In Graph Searching, a team of searchers aims at capturing an invisible fugitive moving arbitrarily fast in a graph. Equivalently, the searchers try to clear a contaminated network. The problem is to compute the minimum number of searchers required to accomplish this task. Several variants of Graph Searching have been studied mainly because of their close relationship with the pathwidth of a graph. Blin et al. defined the Exclusive Graph Searching where searchers cannot "jump" and no node can be occupied by more than one searcher. In [61], we study the complexity of this new variant. We show that the problem is NP-hard in planar graphs with maximum degree 3 and it can be solved in linear time in the class of cographs. We also show that monotone Exclusive Graph Searching is NP-complete in split graphs where Pathwidth is known to be solvable in polynomial time. Moreover, we prove that monotone Exclusive Graph Searching is in P in a subclass of star-like graphs where Pathwidth is known to be NP-hard. Hence, the computational complexities of monotone Exclusive Graph Searching and Pathwidth cannot be compared. This is the first variant of Graph Searching for which such a difference is proved.

6.2.2.3. Diameter of Minimal Separators in Graphs

In [49], we establish general relationships between the topological properties of graphs and their metric properties. For this purpose, we upper-bound the diameter of the *minimal separators* in any graph by a function of their sizes. More precisely, we prove that, in any graph G, the diameter of any minimal separator S in G is at most $\lfloor\frac{\ell(G)}{2}\rfloor \cdot (|S|-1)$ where $\ell(G)$ is the maximum length of an isometric cycle in G. We refine this bound in the case of graphs admitting a *distance preserving ordering* for which we prove that any minimal separator S has diameter at most $2(|S|-1)$. Our proofs are mainly based on the property that the minimal separators in a graph G are connected in some power of G.

Our result easily implies that the *treelength* $tl(G)$ of any graph G is at most $\lfloor\frac{\ell(G)}{2}\rfloor$ times its *treewidth* $tw(G)$. In addition, we prove that, for any graph G that excludes an *apex graph* H as a minor, $tw(G) \leq c_H \cdot tl(G)$ for some constant c_H only depending on H. We refine this constant when G has bounded genus. As a consequence, we obtain a very simple $O(\ell(G))$-approximation algorithm for computing the treewidth of n-node m-edge graphs that exclude an apex graph as a minor in $O(nm)$-time.

6.2.3. Distributed computing with mobile agents

6.2.3.1. Stigmergy of Anonymous Agents in Discrete Environments

Communication by stigmergy consists, for agents/robots devoid of other dedicated communication devices, in exchanging information by observing each other's movements, similar to how honeybees use a dance to inform each other on the location of food sources. Stigmergy, while a popular technique in soft computing (e.g., swarm intelligence and swarm robotics), has received little attention from a computational viewpoint, with only one study proposing a method in a continuous environment. An important question is whether there are limits intrinsic to the environment on the feasibility of stigmergy. While it is not the case in a continuous environment, we show that the answer is quite different when the environment is discrete. In [53], [37], we consider stigmergy in graphs and identifies classes of graphs in which robots can communicate by stigmergy. We provide two algorithms with different tradeoffs. One algorithm achieves faster stigmergy when the density of robots is low enough to let robots move independently. This algorithm works when the graph contains some particular pairwise-disjoint subgraphs. The second algorithm, while slower solves the problem under an extremely high density of robots assuming that the graph admits some large cycle. Both algorithms are described in a general way, for any graph that admits the desired properties and with identified nodes. We show how the latter assumption can be removed in more specific topologies. Indeed, we consider stigmergy in the grid which offers additional orientation information not available in a general graphs, allowing us to relax some of the assumptions. Given an $N \times M$ anonymous grid, we show that the first algorithm requires $O(\mathcal{M})$ steps to achieve communication by stigmergy, where $\mathcal{M}$ is the maximum length of a communication message, but it works only if the number of robots is less than $\lfloor\frac{N \cdot M}{9}\rfloor$. The second algorithm, which requires $O(k^2)$ steps, where k is the number of robots, on the other hand, works for up to $N \cdot M - 5$ robots. In both cases, we consider very weak assumptions on the robots capabilities: i.e., we assume that the robots are anonymous, asynchronous, uniform, and execute deterministic algorithms.

6.2.3.2. Gathering and Exclusive Searching on Rings under Minimal Assumptions

Consider a set of mobile robots with minimal capabilities placed over distinct nodes of a discrete anonymous ring. Asynchronously, each robot takes a snapshot of the ring, determining which nodes are either occupied by robots or empty. Based on the observed configuration, it decides whether to move to one of its adjacent nodes or not. In the first case, it performs the computed move, eventually. The computation also depends on the required task. In [38], we solve both the well-known Gathering and Exclusive Searching tasks. In the former problem, all robots must simultaneously occupy the same node, eventually. In the latter problem, the aim is to clear all edges of the graph. An edge is cleared if it is traversed by a robot or if both its endpoints are occupied. We consider the exclusive searching where it must be ensured that two robots never occupy the same node. Moreover, since the robots are oblivious, the clearing is perpetual, i.e., the ring is cleared infinitely often. In the literature, most contributions are restricted to a subset of initial configurations. Here, we design two different algorithms and provide a characterization of the initial configurations that permit the resolution of the problems under minimal assumptions.

6.2.4. Enhancing the Web's Transparency

Today's Web services – such as Google, Amazon, and Facebook – leverage user data for varied purposes, including personalizing recommendations, targeting advertisements, and adjusting prices. At present, users have little insight into how their data is being used. Hence, they cannot make informed choices about the services they choose.

To increase transparency, we developed *XRay* [40], the first fine-grained, robust, and scalable personal data tracking system for the Web. XRay predicts which data in an arbitrary Web account (such as emails, searches, or viewed products) is being used to target which outputs (such as ads, recommended products, or prices). XRay's core functions are service agnostic and easy to instantiate for new services, and they can track data within and across services. To make predictions independent of the audited service, XRay relies on the following insight: by comparing outputs from different accounts with similar, but not identical, subsets of data, one can pinpoint targeting through correlation. We show both theoretically, and through experiments on Gmail, Amazon, and YouTube, that XRay achieves high precision and recall by correlating data from a surprisingly small number of extra accounts.

6.2.5. 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 [63]. 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.

Consider a set of oligomers listing the subunits involved in sub-complexes of a macro-molecular assembly, obtained e.g. using native mass spectrometry or affinity purification. Given these oligomers, connectivity inference (CI) consists of finding the most plausible contacts between these subunits, and minimum connectivity inference (MCI) is the variant consisting of finding a set of contacts of smallest cardinality. MCI problems avoid speculating on the total number of contacts, but yield a subset of all contacts and do not allow exploiting a priori information on the likelihood of individual contacts. In this context, we present in [43] two novel algorithms, ALGO-MILP-W and ALGO-MILP-WB. The former solves the minimum weight connectivity inference (MWCI), an optimization problem whose criterion mixes the number of contacts and their likelihood. The latter uses the former in a bootstrap fashion, to improve the sensitivity and the specificity of solution sets. Experiments on the yeast exosome, for which both a high resolution crystal structure and a large set of oligomers is known, show that our algorithms predict contacts with high specificity and sensitivity, yielding a very significant improvement over previous work. The software accompanying this paper is made available, and should prove of ubiquitous interest whenever connectivity inference from oligomers is faced.

6.3. Structural Graph Theory

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

More information on several results presented in this section may be found in PhD thesis of A. K. Maia de Oliveira [16], and in the Habilitation thesis of N. Nisse [17].

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-weighting 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 in this case is called the q-backbone chromatic number and is denoted $BBC_q(G,H)$. In [30] and [45], we focus on the case when G is planar and H is a forest. In [30], we give a series of NP-hardness results as well as upper bounds for $BBC_q(G,H)$, depending on the type of the forest (matching, galaxy, spanning tree). We also discuss a circular version of the problem. In [45], we give some upper bounds when G is planar and has no cycles of length 4 an 5, and G is a tree, and we relate those results to the celebrated Steinberg's Conjecture stating that every planar graphs with no cycles of length 4 or 5 is 3-colourable.

In [29], we consider the list version of this problem (in which each vertex is given a particular list of admissible colours), with particular focus on colours in $\mathcal{Z}_p$ – this problem is closely related to the problem of circular choosability. We first prove that the list circular q-backbone chromatic number of a graph is bounded by a function of the list chromatic number. We then consider the more general problem in which each edge is assigned an individual distance between its endpoints, and provide bounds using the Combinatorial Nullstellensatz. Through this result and through structural approaches, we achieve good bounds when both the graph and the backbone belong to restricted families of graphs.

6.3.1.2. On-line colouring graphs with few P_4s

Various on-line colouring procedures are used. The most widespread ones is the greedy one, which results in a greedy colouring. Given a graph $G=(V;E)$, a *greedy colouring* of G is a proper colouring such that, for each two colours $i<j$, every vertex of $V(G)$ coloured j has a neighbour with colour i. A second optimization procedure consists from time to time to consider the present colouring and to free some colour when possible: if each vertex of a colour class has another colour that is not used by its neighbours, we can recolour each vertex in the calls by another colour. This procedure results in a b-colouring of the graph. A *b-colouring* of a graph G is a proper colouring such that every colour class contains a vertex which is adjacent to at least one vertex in every other colour class. One of the performance measure of such graph is the maximum numbers of colours they could possibly use. The greatest k such that G has a greedy colouring with k colours is the *Grundy number* of G. The greatest integer k for which there exists a b-colouring of G with k colours is its *b-chromatic number*. Determining the Grundy number and the b-chromatic number of a graph are NP-hard problems in general. For a fixed q, the $(q;q-4)$-graphs are the graphs for which no set of at most q vertices induces more than $q-4$ distinct induced P_4s paths of order 4). In [24], we obtain polynomial-time algorithms to determine the Grundy number and the b-chromatic number of $(q;q-4)$-graphs, for a fixed q. They generalize previous results obtained for cographs and P_4-sparse graphs, classes strictly contained in the $(q;q-4)$-graphs.

6.3.1.3. 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 [21], [33], we prove that the Weighted Coloring Problem admits a version of the 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, 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 in [21] 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.

6.3.1.4. Inducing proper colourings

Frequently, the proper colouring of the graph must be induced by some other parameters that a vertex can compute locally, for example on looking on the labels assigned to its incident edges or to their orientations.

For a connected graph G of order $|V(G)| \geq 3$ and a k-labelling $c : E(G) \rightarrow \{1, 2, ..., k\}$ of the edges of G, the *code* of a vertex v of G is the ordered k-tuple $(\ell_1, \ell_2, ..., \ell_k)$, where ℓ_i is the number of edges incident with v that are labelled i. The k-labelling c is *detectable* if every two adjacent vertices of G have distinct codes. The minimum positive integer k for which G has a detectable k-labelling is the *detection number* $det(G)$ of G. In [31], we show that it is NP-complete to decide if the detection number of a cubic graph is 2. We also show that the detection number of every bipartite graph of minimum degree at least 3 is at most 2. Finally, we give some sufficient condition for a cubic graph to have detection number 3.

An *orientation* of a graph G is a digraph D obtained from G by replacing each edge by exactly one of the two possible arcs with the same endvertices. For each $v \in V(G)$, the *indegree* of v in D, denoted by $d^-_D(v)$, is the number of arcs with head v in D. An orientation D of G is *proper* if $d^-_D(u) \neq d^-_D(v)$, for all $uv \in E(G)$. The *proper orientation number* of a graph G, denoted by $po(G)$, is the minimum of the maximum indegree over all its proper orientations. In [32], [44], we prove that $po(G) \leq \left(\Delta(G) + \sqrt{\Delta(G)}\right)/2 + 1$ if G is a bipartite graph, and $po(G) \leq 4$ if G is a tree. It is well-known that $po(G) \leq \Delta(G)$, for every graph G. However, we prove that deciding whether $po(G) \leq \Delta(G) - 1$ is already an NP-complete problem on graphs with $\Delta(G) = k$, for every $k \geq 3$. We also show that it is NP-complete to decide whether $po(G) \leq 2$, for planar *subcubic* graphs G. Moreover, we prove that it is NP-complete to decide whether $po(G) \leq 3$, for planar bipartite graphs G with maximum degree 5.

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 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 [16], a number of examples of polynomial instances, several NP-completeness proofs as well as a number of conjectures and open problems are given. In addition, it is conjectured 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. The complexity of finding arc-disjoint branching flows

The concept of arc-disjoint flows in networks is a very general framework within which many well-known and important problems can be formulated. In particular, the existence of arc-disjoint branching flows, that is, flows which send one unit of flow from a given source s to all other vertices, generalizes the concept of arc-disjoint out-branchings (spanning out-trees) in a digraph. A pair of out-branchings $B^+_{s,1}$, $B^+_{s,2}$ from a root s in a digraph $D = (V, A)$ on n vertices corresponds to arc-disjoint branching flows x_1,x_2 (the arcs carrying flow in x_i are those used in $B^+_{s,i}$, $i = 1, 2$) in the network that we obtain from D by giving all arcs capacity $n-1$. It is then a natural question to ask how much we can lower the capacities on the arcs and still have, say, two arc-disjoint branching flows from the given root s. In [46], we prove that for every fixed integer ≥ 2 it is

- an NP-complete problem to decide whether a network $\mathcal{N} = (V, A, u)$ where $u_{ij} = k$ for every arc ij has two arc-disjoint branching flows rooted at s.
- a polynomial problem to decide whether a network $\mathcal{N} = (V, A, u)$ on n vertices and $u_{ij} = n - k$ for every arc ij has two arc-disjoint branching flows rooted at s.

The algorithm for the later result generalizes the polynomial algorithm, due to Lovász, for deciding whether a given input digraph has two arc-disjoint out-branchings rooted at a given vertex. Finally we prove that under the so-called Exponential Time Hypothesis (ETH), for every $\epsilon > 0$ and for every $k(n)$ with $(\log(n))^{1+\epsilon} \leq k(n) \leq \frac{n}{2}$ (and for every large i we have $k(n) = i$ for some n) there is no polynomial algorithm for deciding whether a given digraph contains two arc-disjoint branching flows from the same root so that no arc carries flow larger than $n - k(n)$.

6.3.2.3. Splitting a tournament into two subtournaments with given minimum outdegree

A (k_1, k_2)*-outdegree-splitting* of a digraph D is a partition (V_1, V_2) of its vertex set such that $D[V_1]$ and $D[V_2]$ have minimum outdegree at least k_1 and k_2, respectively. In [58], we show that there exists a minimum function f_T such that every tournament of minimum outdegree at least $f_T(k_1, k_2)$ has a (k_1, k_2)-outdegree-splitting, and $f_T(k_1, k_2) \leq k_1^2/2 + 3k_1/2 + k_2 + 1$. We also show a polynomial-time algorithm that finds a (k_1, k_2)-outdegree-splitting of a tournament if one exists, and returns 'no' otherwise. We give better bound on f_T and faster algorithms when $k_1 = 1$.

6.3.2.4. Eulerian and Hamiltonian dicycles in directed hypergraphs

In [19], we generalize the concepts of Eulerian and Hamiltonian digraphs to directed hypergraphs. A *dihypergraph* H is a pair $(\mathcal{V}(H), \mathcal{E}(H))$, where $\mathcal{V}(H)$ is a non-empty set of elements, called *vertices*, and $\mathcal{E}(H)$ is a collection of ordered pairs of subsets of $\mathcal{V}(H)$, called *hyperarcs*. It is Eulerian (resp. Hamiltonian) if there is a dicycle containing each hyperarc (resp. each vertex) exactly once. We first present some properties of Eulerian and Hamiltonian dihypergraphs. For example, we show that deciding whether a dihypergraph is Eulerian is an NP-complete problem. We also study when iterated line dihypergraphs are Eulerian and Hamiltonian. Finally, we study when the generalized de Bruijn dihypergraphs are Eulerian and Hamiltonian. In particular, we determine when they contain a complete Berge dicycle, i.e. an Eulerian and Hamiltonian dicycle.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. Amadeus (May 2014 - April 2015)

Participants: Marco Biazzini, David Coudert, Stéphane Pérennes, Michel Syska.

> Duration: May 2014 - April 2015
>
> Inria teams: Scale, Coati
>
> Abstract: This collaboration aims to assess the benefits that digital technologies can bring in complex travel distribution applications. Indeed, these applications require both high performance algorithms and distributed programming methods to search for the best solutions among billions of combinations, in a very short time thanks to the simultaneous use of several hundreds (if not thousands) of computers. These benefits will be demonstrated in an application to build 'off the shelf' optimized packages, fully customized to best meet the complex demands of the traveler.

7.2. Bilateral Grants with Industry

7.2.1. 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*.

7.2.2. Contract CIFRE with KONTRON, 11/2011 - 4/2015

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.

7.2.3. 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 joint laboratory Inria / Alcatel-Lucent Bell-labs France within the ADR Network Science and works on the fast computation of topological properties (hyperbolicity, covering, etc.).

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

8.1.1.1. ANR Blanc STINT, 2014-2017

Participants: Jean-Claude Bermond, David Coudert, Frédéric Havet, Luc Hogie, Ana Karolinna Maia de Oliveira, Nicolas Nisse, Stéphane Pérennes, Michel Syska.

The STINT projet (*STructures INTerdites*) is leaded by the MC2 group (LIP, ENS-Lyon) and involves the G-SCOP laboratory (Grenoble).

The aim of STINT is to answer the following fondamental question: *given a (possibly infinite) family ψ of graphs, what propoerties does a ψ-free graph have?*. To this end, it will firstly establish bounds on some classical graph parameters (e.g., clique number, stability number, chromatic number) for ψ-free graphs. Then, it will design efficient algorithms to recognize ψ-free graphs and to determine or approximate some parameters for those graphs. These studies shall result in the development of new proof techniques.

(http://www.ens-lyon.fr/LIP/MC2/STINT/)

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://gtgraphes.labri.fr/)

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

8.2.1.1. EULER

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

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 with Major European Organizations

Participants: David Coudert, Alvinice Kodjo, Truong Khoa Phan.

Discrete Optimization group : Lehrstuhl II für Mathematik, RWTH Aachen (Germany)

Robust optimization in backbone networks for energy efficient designs, and chance-constrained programming in backhaul networks subject to link capacity variations.

8.2.3. COLOR Inria Sophia Antipolis-méditerranée DIT University of Athens

Participants: Jean-Claude Bermond, David Coudert, Frédéric Giroire, Nicolas Nisse, Stéphane Pérennes.

Title : Algorithms Design and Games for Location, Placement and Infrastructure Leasing (AlGaLoP)

Duration: June 2013- September 2014

COATI and DIT University of Athens (responsible Vassilis Zissimopoulos)

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. Participation In other International Programs

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

GAIATO : Graphs And Algorithms Applied To Telecommunications, International Cooperation FUNCAP/FAPs/Inria/INS2i-CNRS, no. INC-0083-00047.01.00/13, with Federal University of Ceara, Brasil, 2014-2016.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

8.4.1.1. Professors / Researchers

Xavier Défago

Date: until Jan 31 2014
Institution: JAIST, Japan

Michele Flammini
Date: Jun 30 - Jul 13 2014
Institution: Univ. L'aquila, Italy

Brigitte Jaumard
Date: Dec 15-21, 2014
Institution: Concordia Univ., Montréal, Canada

Mejdi Kaddour
Date: Oct 13-19 2014
Institution: Univ. Oran, Algeria

Takako Kodate
Date: Mars 21 - Apr 3 2014
Institution: Tokyo Woman's Christian Univ., Suginami-ku, Tokyo, Japan

Arie M. C. A. Koster
Date: Jun 10-13, 2014
Institution: RWTH Aachen Univ., Germany

Gianpiero Monaco
Date: Jul 9-17, 2014
Institution: Univ. L'aquila, Italy

Gabriele Muciaccia
Date: Jan 10-16, 2014
Institution: Royal Holloway, University of London, UK

Jean-Sébastien Sereni
Date: Fev 2-7, 2014
Institution: LORIA, Nancy, France

Julio-Cesar Silva Araújo
Date: Jun 23 - Jul 25 2014
Institution: Univ. Federal do Ceara, Fortaleza, Brazil

Karol Suchan
Date: Sep 7-28 2014
Institution: Univ. Adolfo Ibanez, Santiago, Chile

Joseph Yu
Date: Mar 1 - Apr 18, 2014
Institution: Abbotsford and SFU, Vancouver, Canada

Vassilis Zissimopoulos
Date: Jul 4-12 2014
Institution: NKUA, Athens, Greece

8.4.1.2. PhD students

Marthe Bonamy
Date: Jan 27 - Fev 7, 2014
Institution: LIRMM, Montpellier, France

- Akram Kout
  - Date: Sep 1 - Oct 25, 2014
  - Institution: Univ. Mentouri, Constantine, Algeria,
- Esteban H. Roman Catafau
  - Date: May 8 - Jul 23 2014
  - Institution: Univ. Adolfo Ibanez, Santiago, Chile

8.4.1.3. Internships

- Claudio Carvallho
  - Date: Dec 2013-Feb 2014
  - Institution: Federal University of Ceara, Brasil
  - Supervisor: Frédéric Havet
- Renan Dantas
  - Date: Dec 2013-Feb 2014
  - Institution: Federal University of Ceara, Brasil
  - Supervisor: Frédéric Havet
- Doldan Juan
  - Date: Apr 2014 - Aug 2014
  - Institution: Universidad de Buenos Aires (Argentina)
  - Supervisor: Nicolas Nisse

8.4.2. Visits to International Teams

8.4.2.1. Research stays abroad

- Jean-Claude Bermond
  - Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens, Greece, May 31 -June 14, 2014
- David Coudert
  - Research Unit 1 (RU1) of the Computer Technology Institute and Press "Diophantus" (CTI), Patras, Greece, March 12-16, 2014
  - Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens, Greece, March 16-22, 2014
  - Univ. Adolfo Ibañez, Santiago, Chile, November 17-30, 2014
- Frédéric Giroire
  - LIAFA, Paris, France, March 19, 2014
  - PARGO, Federal University of Ceará, Fortaleza, Brazil, June 9-20, 2014
- Frédéric Havet
  - LIP, ENS Lyon, France, December 15-17, 2014
- Nicolas Nisse
  - JAIST, Kanazawa, Japan, July 22 - August 8, 2014
  - Univ. Adolfo Ibañez, Santiago, Chile, November 17 - December 12, 2014

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. General chair, scientific chair

Jean-Claude Bermond :

Mediterranean Days 2014, March 12-14 (http://campus.sophiatech.fr/meddays2014/)

Frédéric Giroire :

ResCom'14 : school of the *pôle ResCom of GDR ASR of CNRS* on "Network Science", Furiani, Corsica, May 12-16, 2014

Workshop "Energy Aware Networks" of the labex UCN@Sophia (http://www.ucnlab.eu/fr/node/66), Sophia Antipolis, October 14, 2014

Nicolas Nisse :

GRASTA'14 : 6th Workshop on GRAph Searching, Theory and Applications [54], Cargèse, Corsica, France, March 31th-April 4th, 2014

9.1.1.2. *Member of the organizing committee*

Christelle Caillouet :

ResCom'14 : school of the *pôle ResCom of GDR ASR of CNRS* on "Network Science", Furiani, Corsica, May 12-16, 2014

Frédéric Havet :

Bondy is 70 : Paris, France, November 17, 2014;

9.1.2. Scientific events selection

9.1.2.1. *Chair of conference program committee*

David Coudert :

Co-chair of ResCom'14, school of the *pôle ResCom of GDR ASR of CNRS* on "Network Science", Furiani, Corsica, May 12-16, 2014

9.1.2.2. *Member of the conference program committee*

David Coudert :

ROADEF'14 : 15ème congrès annuel de la Société française de recherche opérationnelle et d'aide à la décision, Bordeaux, France

ONDM'14 : 18th International Conference on Optical Networking Design and Modeling, Stockholm, Sweden, May 19-22, 2014

IEEE ICC'14 : IEEE International Conference on Communications, Sydney, Australia, June 10-14, 2014

IEEE Globecom'14 : IEEE Global Communications Conference, Austin, TX, USA, December 8-12, 2014

Frédéric Havet :

WG'14 : 40th International Workshop on Graph-Theoretic Concepts in Computer Science, Orléans, France, June 25-27, 2014;

ICGT'14 : 9th International Colloquium on Graph Theory and combinatorics, Grenoble, France, June 30-July 4, 2014;

BGW'14 : Bordeaux Graph Workshop, Bordeaux, France, November 19-22 2014;

Nicolas Nisse :

16es Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications (AlgoTel 2014), Ile de Ré, France, 3-6 June, 2014.

9.1.3. Journal

9.1.3.1. *Member of the editorial board*

Jean-Claude Bermond :

Combinatorics Probability and Computing

Computer Science Reviews

Discrete Applied Mathematics

Discrete Mathematics

Discrete Mathematics, Algorithms and Applications

Journal of Graph Theory

Journal of Interconnection Networks (Advisory Board)

Mathématiques et Sciences Humaines

Networks (Wiley)

Parallel Processing Letters

SIAM book series on Discrete Mathematics, Transactions on Network Optimization and Control, Discrete Mathematics, Algorithms and Applications

David Coudert :

Discrete Applied Mathematics (Elsevier)

Networks (Wiley)

Frédéric Havet :

Discrete Mathematics and Theoretical Computer Science

9.1.4. Steering committees

David Coudert :

Pôle ResCom du GDR ASR du CNRS (since 2005)

Rencontres francophones sur les aspects algorithmiques des télécommunications (AlgoTel)

Frédéric Havet :

GT Graphes du GDR IM du CNRS

Ecole de Printemps de Théorie des Graphes

Journée Combinatoire et Algorithmes du Littoral Méditerranéen

9.1.5. Participation in conferences

ICDCN : 15th International Conference on Distributed Computing and Networks, January 4-7 2014, Coimbatore, India. Attended by Nicolas Nisse.

ROADEF : 15ème congrès annuel de la Société française de recherche opérationnelle et d'aide à la décision, Bordeaux, France, February 26-28. Attended by David Coudert and Alvinice Kodjo (speaker);

STACS : 31st Symposium on Theoretical Aspects of Computer Science, March 5-8 2014, Lyon, France. Attended by Nicolas Nisse.

GRASTA : 6th Workshop on GRAph Searching, Theory and Applications, March 31th-April 4th, 2014, Cargèse, Corsica, France. Attended by David Coudert (speaker), Nicolas Nisse (speaker and organiser), and Stéphane Pérennes.

Nice Workshop on Random Graphs : May 14-15, 2014, Nice, France. Attended by Nicolas Nisse.

ResCom : school of the *pôle ResCom of GDR ASR of CNRS* on "Network Science", Furiani, Corsica, May 12-16, 2014. Attended by David Coudert (Lecturer)

AlgoTel : 16es Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications (AlgoTel 2014), 3-6 June, 2014, Ile de Ré, France. Attended by Fatima Zahra Moataz (speaker), David Coudert, Nicolas Nisse, T. K. Phan (speaker);

WG : 40th International Workshop on Graph-Theoretic Concepts in Computer Science, Orléans, France (June 25-27, 2014). Attended by Frédéric Havet;

SEA : Symposium on Experimental Algorithms, Copenhagen, Denmark, June 29 - July 1st, 2014. Attended by David Coudert (speaker).

ICGT : 9th International colloquium on graph theory and combinatorics, June 30-July 4, 2014, Grenoble, France. Attended by Frédéric Havet and Nicolas Nisse.

MAC : Moving and Computing. Research Meeting on Distributed Computing by Mobile Robots, July 26th 2014, Hida Takayama, Japan. Attended by Nicolas Nisse.

IWOCA : 25th International Workshop on Combinatorial Algorithms, Duluth, Minnesota, USA (October 15-17, 2014). Attended by Benjamin Momège (speaker);

BGW : Bordeaux Graph Workshop, Bordeaux, France, November 19-22 2014. Attended by Frédéric Havet;

Globecom : IEEE Global Communications Conference, Austin, United States (December 8-12, 2014). Attended by Frédéric Giroire (speaker)

9.1.6. Participation in scientific meetings

STINT : Kick off meeting of ANR STINT, Lyon, February 17-18, 2014. Attended by Jean-Claude Bermond, Frédéric Havet and Stéphane Pérennes;

FIA : Future Internet Assembly, Athens, Greece, March 18-20, 2014. Attended by David Coudert;

EULER : Plenary meeting of FP7 STREP EULER, Paris, France (March 27-28, 2014). Attended by David Coudert;

JSInria : Journées Scientifiques Inria, Lille, France, June 25-27, 2014. Attended by David Coudert (speaker);

EULER : Final review meeting of FP7 STREP EULER project, Brussels, Belgium (August 29, 2014). Attended by David Coudert;

STINT : workshop of ANR STINT, Vercors, France, September 24-26 2014. Attended by Frédéric Havet

Seminar Orange/Inria : Common seminar Orange/Inria, Paris, France, October 28, 2014 Attended by Joanna Moulierac;

Inria-Industrie : Rencontre Inria Industrie "Télécoms du futur", November, 13 2014. Attended by Joanna Moulierac.

9.1.7. Participation in committees

Jean-Claude Bermond :

Expert for DRTT, and various projects outside France (Canada, italie, ...)

David Coudert :

Expert for the Future and Emerging Technologies Open Scheme (FET-Open) European program, and the ANR

Frédéric Giroire :

Elected member of I3S laboratory committee since 2012

Frédéric Havet :

Responsible of Pôle ComRed of I3S laboratory;

Expert for the ANR and its Czech analogues;

Nicolas Nisse :

Expert for the ANR

Michel Syska :

Expert for DRTT PACA

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence

Alvinice Kodjo, *Informatique Pratique*, 40h ETD, Level L1, UNS;

Alvinice Kodjo, *Réseaux (Couches supérieures)*, 15h ETD, Level L3, UNS;

Fatima Zahra Moataz, *Programmation avec Python*, 12h ETD, Level L1, Université Nice-Sophia Antipolis;

Fatima Zahra Moataz, *Systèmes Informatiques*, 24h ETD, Level L1, Université Nice-Sophia Antipolis;

Christelle Molle-Caillouet, *IT Tools*, 53h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

Christelle Molle-Caillouet, *Database and advanced information system*, 36h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Christelle Molle-Caillouet, *Operations Research*, 81h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Christelle Molle-Caillouet, *Delivery Optimization*, 30h ETD, Level L3, IUT Nice Côte d'Azur, UNS;

Benjamin Momège, *Mathématiques Discrètes*, 75h ETD, Level L3, Polytech'Nice Sophia, UNS;

Joanna Moulierac, *Algorithms and Programming*, 100h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

Joanna Moulierac, *Networks, basics and Advanced Networks*, 150h ETD, Level L1 and L2, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Introduction to Operating Systems*, 40h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Operating Systems : Advanced Programming*, 60h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Bash Scripting*, 40h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Introduction to Algorithms*, 30h ETD, Level L3, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Linux Systems Administration*, 40h ETD, Level L3, IUT Nice Côte d'Azur, UNS;

Master

David Coudert, *Algorithms for Telecoms*, 32h ETD, stream UbiNet of Master 2 IFI and Master RIF, UNS;

Frédéric Giroire, *Algorithmics of Telecommunications*, 18h ETD, stream UbiNet of Master 2 IFI and Master RIF, UNS;

Frédéric Giroire, *Green Networks*, 15h ETD, stream UbiNet of Master 2 IFI, UNS;

Frédéric Giroire, *Introduction to probability and statistics*, 15h ETD, International Master 1, UNS;

Frédéric Havet, *Optimisation combinatoire*, 24 ETD, Master 1 and 2, UNS, France;

School

David Coudert, *the notion of hyperbolicity in graphs*, 2h ETD, Summer school ResCom;

9.2.2. Teaching administration

Collaboration Inria-Lycée International de Valbonne

Nicolas Nisse : co-responsible of the Computer Science course of MPSI;

IUT Nice Côte d'Azur

Joanna Moulierac, Directrice d'études of Semestre 2 décalé at IUT Nice Côte d'Azur, Computer Science Department since september 2013;

Michel Syska, responsible of the Computer Science Department of IUT form September 2011 till September 2014. He has organized the national meeting of the 46 CS departements, Nice, October 16-17.

Stream Ubinet, Master 2 IFI (http://ubinet.unice.fr)

Jean-Claude Bermond, member of the scientific committee;

Frédéric Giroire, responsible of the Internships, since October 2011;

International Master 1 (http://computerscience.unice.fr/master1)

Jean-Claude Bermond, member of the scientific committee of the international track of the M1

9.2.3. Supervision

9.2.3.1. HdR

Nicolas Nisse, "Algorithmic complexity: Between Structure and Knowledge How Pursuit-evasion Games help" [17], Université Nice Sophia Antipolis, May 23, 2014

9.2.3.2. PhD

Alvinice Kodjo, "Design and Optimization of Wireless Backhaul Networks" [13], Université Nice Sophia Antipolis, December 18, 2014. Supervisor: David Coudert

Aurélien Lancin, "Étude de réseaux complexes et de leurs propriétés pour l'optimisation de modèles de routage" [14], Université Nice Sophia Antipolis, December 9, 2014. Supervisor: David Coudert

Bi Li, "Tree Decompositions and Routing Problems" [15], Université Nice Sophia Antipolis, November 12, 2014. Supervisors: David Coudert and Nicolas Nisse Computer Science, date de soutenance, encadrant(s)

Ana Karolinna Maia De Oliveira, "Subdivisions of Digraphs" [16], Université Nice Sophia Antipolis, November 5, 2014. Supervisor: Frédéric Havet

Truong Khoa Phan, "Design and Management of Networks with Low Power Consumption" [18], Université Nice Sophia Antipolis, September 25, 2014. Supervisors: David Coudert and Joanna Moulierac

9.2.3.3. PhD in progress

Guillaume Ducoffe, "Metric properties of large graphs", since September 2014. Supervisor: David Coudert

Nicolas Huin, "Energy-Efficient Software Defined Networks", since October 2014. Supervisor: Frédéric Giroire and Dino Lopez (I3S)

Fatima Zahra Moataz, "Design and optimization of networks subject to failure and link capacity variations", since October 2012. Supervisor: David Coudert

Sebastien Felix, "Smart transports : optimisation du trafic dans les villes", since January 2011. Supervisors: Jean-Claude Bermond and Jérôme Galtier

9.2.3.4. Internship

Paul Bertot (IUT Nice Côte d'Azur, France), "distributed computing of the diameter of large graphs", November-February (3 months). Supervisor: Michel Syska;

Eneina Gjata (Master 2 IFI, parcours ubinet, University Nice-Sophia Antipolis, France), "Analysis of protocols for Data Redundancy Elimination", March-August 2014 (6 months). Supervisor: Joanna Moulierac

Nicolas Huin (Master 2 RIF, University Nice-Sophia Antipolis, France), "Study of a Distributed Live Video Streaming System", March-August 2014 (6 months). Supervisor: Frédéric Giroire

Flavian Jacquot (IUT Nice Côte d'Azur, France), "distributed computing frameworks for large graphs", November-March (4 months). Supervisor: Luc Hogie;

William Lochet (ENS, Lyon, France), pre-doctoral internship on "Subdivision of oriented cycles in digraphs", October-December 2014 (3 months). Supervisor: Frédéric Havet

Alexandros Panagiotidis (International Master 1, University Nice-Sophia Antipolis, France), "Connectivity Inference in Structural Proteomics", May-August 2014 (4 months). Supervisors: David Coudert, Christelle Caillouet

Thomas Wattrelot (Master 1 MAM, Polytech'Nice, UNS), "Comparison of algorithms for the traveling salesman problem", July-August 2014 (2 months). Supervisor: David Coudert

9.2.4. Juries

David Coudert :

- Member of the HdR jury of Nicolas Nisse, Univ. Nice Sophia Antipolis, May 23, 2014
- Member of the PhD jury of François Clad, Univ. Strasbourg, September 22, 2014
- Member of the PhD jury of Truong Khoa Phan, Univ. Nice Sophia Antipolis, September 25, 2014
- Member of the PhD jury of Bi Li, Univ. Nice Sophia Antipolis, November 12th, 2014
- Referee and member of the PhD jury of Massinissa Merabet, Univ. Montpellier, December 5, 2014
- Member of the PhD jury of Aurélien Lancin, Univ. Nice Sophia Antipolis, December 9, 2014
- Referee and member of the PhD jury of Stéphane Raux, Univ. Paris Diderot, December 12, 2014
- Member of the PhD jury of Alvinice Kodjo, Univ. Nice Sophia Antipolis, December 18, 2014

Frédéric Giroire :

- Member of the PhD jury of Alain Julé, Université de Cergy-Pontoise, March 7, 2014

Frédéric Havet :

- Referee and member of the PhD jury of Julien Bensmail, University of Bordeaux, June 10, 2014
- Referee and member of the PhD jury of Remi Watrigant, University Montpellier 2, October 2, 2014
- Member of the PhD jury of Ana Karolinna Maia De Oliveira, Univ. Nice Sophia Antipolis, November 5, 2014
- Referee and member of the PhD jury of Maxime Cochefert, University of Metz, December 18, 2014

Joanna Moulierac :

- Member of the PhD jury of Truong Khoa Phan, Univ. Nice Sophia Antipolis, September 25, 2014

Nicolas Nisse :

- Member of the PhD jury of Bi Li, Univ. Nice Sophia Antipolis, November 12, 2014

9.2.5. Participation in committees

Jean-Claude Bermond :

Member of the Ph.D. committee of the University of Marseille

Responsible of the Attractivity for Inria Sophia Antipolis - Méditerranée and more generally for the Campus Sophia Tech

David Coudert :

Member of doctoral committee (CSD) of Inria Sophia Antipolis - Méditerranée, since 2009

Nicolas Nisse :

Member of a comité de sélection of 27me section, Univ. Aix-Marseille

Frédéric Havet :

President of a *comité de sélection* of 27eme section of UNS;

Member of a *comité de sélection* of 27eme section of Aix-Marseille Université;

Joanna Moulierac

Member of the *comité de sélection 27e section* of Univ. Nice Sophia Antipolis

9.3. Popularization

- Fête de la Science

  Frédéric Giroire presented the stand "Mathémagie" (Magie et Mathématiques) at Rians, France, October 13-18, 2014;

  Frédéric Havet organized the "Village des Sciences de Rians", October 13-18 (900 attendants) and created several stands and trained some people to conduct them;

  Frédéric Havet presented the stand "Pavages: art, preuves et jeux" at Rians, France, October 13-18, 2014.

- Institut Esope - Maison des Sciences de Rians

  Frédéric Havet is vice-president of the association Esope 21 whose aim is scientific and literary popularization. He organized many local events and conducted various discovery workshops in elementary and secondary schools. In total , in spoke in front of about 30 classes on various topics (Mathematics, Computer Science, Astronomy, Ornithology, Job in research, etc.).

10. Bibliography

Major publications by the team in recent years

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[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

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[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

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[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

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Doctoral Dissertations and Habilitation Theses

[13] A. Kodjo. *Design and Optimization of Wireless Backhaul Networks*, Université Nice Sophia Antipolis, December 2014, https://hal.inria.fr/tel-01099987

[14] A. Lancin. *Study of complex networks properties for the optimization of routing models*, Université de Nice - Sophia Antipolis, December 2014, https://hal.inria.fr/tel-01097314

[15] B. Li. *Tree Decompositions and Routing Problems*, Université de Nice - Sophia Antipolis, November 2014, https://hal.archives-ouvertes.fr/tel-01083646

[16] A. K. Maia de Oliveira. *Subdivisions of Digraphs*, Université de Nice - Sophia Antipolis, November 2014, https://hal.inria.fr/tel-01086779

[17] N. Nisse. *Algorithmic complexity: Between Structure and Knowledge How Pursuit-evasion Games help*, Université Nice Sophia Antipolis, May 2014, Habilitation à diriger des recherches, https://tel.archives-ouvertes.fr/tel-00998854

[18] T. K. Phan. *Design and Management of Networks with Low Power Consumption*, Universite de Nice-Sophia Antipolis, September 2014, https://hal.inria.fr/tel-01078087

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