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Activity Report 2015

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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Creation of the Team: 2013 January 01, updated into Project-Team: 2013 January 01

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Other Research Topics and Application Domains:

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1. Members

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Nicolas Nisse [Inria, Researcher, HdR]
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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 mainly in telecommunication networks.

The main 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, Algorithmics, and Operations Research 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.

COATI also investigates other application areas such as bio-informatics, transportation networks and economics.

The research done in COATI results in the production of advanced software such as GRPH, and in the contribution to large open source software such as Sagemath.

3. Research Program

3.1. Research Program

Members of COATI have a strong 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 aggregation 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 fundamental 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 and Software-Defined Networks (SDN)** at both the design and management levels. More precisely, we plan to study the deployment of energy-efficient routing algorithm within SDN. We developed new algorithms in order to take into account the new constraints of SDN equipments and we evaluate their performance by simulation and by experimentation on a fat-tree architecture.
- **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, as we did in the context of the FP7 EULER led 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 experts 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 7.2). Furthermore, we are working on robot moving problems coming from Artificial Intelligence/Robotic in collaboration with Japan Advanced Institute of Science and Technology. In the area of transportation networks, we have started a collaboration with Amadeus on complex trip planning, and a collaboration with SME Instant-System on dynamic car-pooling combined with multi-modal transportation systems. Last, we have started a collaboration with GREDEG (Groupe de Recherche en Droit, Economie et Gestion, Univ. Nice Sophia Antipolis) on the analysis and the modeling of systemic risks in networks of financial institutions.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

Bi Li, former PhD student of COATI, is recipient of the Chinese government award for outstanding self-financed students abroad, edition 2014, for her PhD thesis entitled "Tree Decompositions and Routing Problems".

Fatima Zahra Moataz received the best student paper award of the conference ALGOTEL 2015.

BEST PAPER AWARD:

[51]
F. ZAHRA MOATAZ. *On Spectrum Assignment in Elastic Optical Tree-Networks*, in "ALGOTEL 2015 — 17èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications", Beaune, France, June 2015, https://hal.archives-ouvertes.fr/hal-01142818

6. New Software and Platforms

6.1. Grph

Participants: Luc Hogie [Contact], Nathann Cohen, David Coudert.

FUNCTIONAL DESCRIPTION

GRPH is an open-source Java library for the manipulation of graphs. In 2015, the library has been maintained and augmented for users needs, especially with a new algorithm for iterating over the cycles of a given graph. This was requested by the EPI AOSTE for the TimeSquare tool.

URL: http://www.i3s.unice.fr/~hogie/grph/

6.2. JourneyPlanner

Participant: Marco Biazzini [Contact].

FUNCTIONAL DESCRIPTION

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.

6.3. Sagemath

Participants: David Coudert [Contact], Nathann Cohen.

SCIENTIFIC DESCRIPTION

Sagemath is a free open-source mathematics software system initially created by William Stein (Professor of mathematics at Washington University). It builds on top of many existing open-source packages: NumPy, SciPy, matplotlib, Sympy, Maxima, GAP, FLINT, R and many more. Access their combined power through a common, Python-based language or directly via interfaces or wrappers.

OUR CONTRIBUTION

We contribute the addition of new graph algorithms to Sagemath, along with their documentation and the improvement of underlying data structures.

URL : http://www.sagemath.org/

6.4. TripPlanner

Participants: David Coudert [Contact], Stéphane Pérennes.

FUNCTIONAL DESCRIPTION

TripPlanner is a tool for computing a minimum cost trip across multiple cities when neither the order in which to visit the cities nor the sojourn duration in these cities are fully specified. The cost of a trip includes both the price of all airplane tickets necessarily for the trip plus the price of the hotels (both costs depend on the exact travel date) at which the user will sojourn. The trip planner is also able to compute the k cheapest trips.

TripPlanner is written in Python and uses the linear programming interface of Sagemath.

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

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6.5. Platforms

6.5.1. BigGraphs

Participants: Luc Hogie [Contact], Nicolas Chleq [SED-SOP], Michel Syska [Coordinator], David Coudert, Paul Bertot, Flavian Jacquot, Arnaud Legout [DIANA], Fabrice Huet [SCALE], Éric Madelaine [SCALE].

FUNCTIONAL DESCRIPTION

The objective of BigGraphs is to provide a distributed platform for very large graphs processing. A typical data set for testing purpose is a sample of the Twitter graph with 3 millions of nodes and 200 millions of edges. Last year we started the project with the evaluation of existing middlewares (GraphX/Spark and Giraph/Hadoop). After having tested some useful algorithms (written in the BSP model) we decided to develop our own platform.

This platform is based on the existing BIGGRPH library and this year we have focused on the quality and the improvement of the code. In particular we have designed strong test suites and some non trivial bugs have been fixed. We also have implemented specific data structures for BSP and support for distributed debugging. This comes along with the implementation of algorithms such as BFS or strongly connected components that are run on the NEF cluster.

This project is a joint work of the three EPI COATI, DIANA and SCALE and is supported by an ADT grant.

URL: http://www.i3s.unice.fr/~hogie/software/index.php?name=grph

The following software are useful tools that bring basic services to the platform (they are not dedicated to BIGGRPH).

JAC-A-BOO: is a framework aiming at facilitating the deployment of distributed Java scientific applications over clusters and is used to start BIGGRPH. computers.
LDJO: (Live Distributed Java Objects) is a framework for the development and the deployment of Java distributed data structures
OCTOJUS: provides an object-oriented RPC (Remote Procedure Call) implementation in Java
Participants : Luc Hogie [Contact], Nicolas Chleq
URL : http://www.i3s.unice.fr/~hogie/ {jacaboo,ldjo,octojus}

7. New Results

7.1. Network Design and Management

Participants: Jean-Claude Bermond, Christelle Caillouet, David Coudert, Frédéric Giroire, Frédéric Havet, Nicolas Huin, Alvinice Kodjo, Fatima Zahra Moataz, Joanna Moulierac, Nicolas Nisse, Stéphane Pérennes.

7.1.1. Wireless Networks

7.1.1.1. Dimensioning Microwave Wireless Networks

In [47], we aim at dimensioning fixed broadband microwave wireless networks under unreliable channel conditions. As the transport capacity of microwave links is prone to variations due to, e.g., weather conditions, such a dimensioning requires special attention. It can be formulated as the determination of the minimum cost bandwidth assignment of the links in the network for which traffic requirements can be met with high probability, while taking into account that transport link capacities vary depending on channel conditions. The proposed optimization model represents a major step forward since we consider dynamic routing. Experimental results show that the resulting solutions can save up to 45% of the bandwidth cost compared to the case where a bandwidth over-provisioning policy is uniformly applied to all links in the network planning. Comparisons with previous work also show that we can solve much larger instances in significantly shorter computing times, with a comparable level of reliability.

7.1.1.2. Data Gathering and Personalized Broadcasting in Radio Grids with Interference

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, two calls interfere in a step, if one sender is at distance at most dI from the other receiver. 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 [24], 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 $dI \in \{0, 1, 2\}$. In particular, we present an algorithm that achieves the optimal makespan up to an additive constant 2 when $dI = 0$. 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 $dI = 0$, 4 when $dI = 2$, and 3 when both $dI = 1$ 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.

7.1.2. Elastic Optical Networks

7.1.2.1. On Spectrum Assignment in Elastic Optical Tree-Networks

To face the explosion of the Internet traffic, a new generation of optical networks is being developed; the Elastic optical Networks (EONs). The aim with EONs is to use the optical spectrum efficiently and flexibly. The benefit of the flexibility is, however, accompanied by more difficulty in the resource allocation problems. In [54], [51], [14], we study the problem of Spectrum Allocation in Elastic Optical Tree-Networks. In trees, even though the routing is fixed, the spectrum allocation is NP-hard. We survey the complexity and approximability results that have been established for the SA in trees and prove new results for stars and binary trees.

7.1.3. Fault Tolerance

7.1.3.1. 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 [59], we extend these notions to characterize new cases in which these optimization problems can be solved in polynomial time. We also investigate 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.

In [22], we investigate the k-diverse routing problem which is to find a set of k pairwise SRLG-disjoint paths between a given pair of end nodes of the network. This problem has been proven NP-complete in general and some polynomial instances have been characterized. We consider more specifically the case where the SRLGs are localized and satisfy the star property. We first provide counterexamples to the polynomial time algorithm proposed by X. Luo and B. Wang (DRCN'05) 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 then characterize 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. Finally we consider the problem of finding the maximum number of SRLG-disjoint paths in networks with SRLGs satisfying the star property. We prove that this problem is NP-hard to approximate within $O(|V|^{1-\varepsilon})$ for any $0 < \varepsilon < 1$, where V is the set of nodes in the network. Then, we provide exact and approximation algorithms for relevant subcases.

7.1.3.2. Design of Fault-tolerant On-board Networks with Variable Switch Sizes

In [29], we focus on designing networks that are capable, in the presence of faulty output ports, of rerouting input signals to operational output ports. Since the components of a satellite cannot be repaired, redundant amplifiers are added, and the interconnection network satisfies the following fault tolerance property: the network connects the set of input ports with the set of output ports, and for any set of at most k output port failures, there exists a set of edge-disjoint paths connecting the input ports to the operational output ports. Since each switching device is expensive, these interconnection networks are constructed using the fewest possible switches, or at least a number of switches close to the minimum value. The networks are controlled centrally from Earth. Each time an amplifier in use develops a fault, the controller sends messages to the switches to change their settings, so as to ensure that the inputs remain connected to functioning amplifiers.

Current switches have four ports. Obviously, the larger the number of ports, the more expensive will be the switches, but then fewer will be required. So the cost of such a network involves a trade-off between the total number of switches and their unit cost. In order to determine the minimum-cost network, we give some bounds on the minimum number $\mathcal{N}(n,k,r)$ of $2r$-port switches in interconnection networks with n inputs and $n+k$ outputs.

We first show $\mathcal{N}(n,k,r) \leq \left\lceil \frac{k+2}{2r-2} \right\rceil \left\lceil \frac{n}{2} \right\rceil$. When $r \geq k/2$, we prove a better upper bound: $\mathcal{N}(n,k,r) \leq \frac{r-2+k/2}{r^2-2r+k/2} n + O(1)$. Next, we establish some lower bounds. We show that if $k \geq r$, then $\mathcal{N}(n,k,r) \geq \frac{3n+k}{2r}$. We improve this bound when $k \geq 2r$: $\mathcal{N}(n,k,r) \geq \frac{3n+2k/3-r/2}{2r-2+\frac{3r}{\lfloor \frac{k}{r} \rfloor}}$. Finally, we determine $\mathcal{N}(n,k,r)$ up to additive constants for $k \leq 6$.

7.1.4. Reducing Networks' Energy Consumption

Due to the increasing impact of ICT (Information and Communication Technology) on power consumption and worldwide gas emissions, energy efficient ways to design and operate backbone networks are becoming a new concern for network operators. Recently, energy-aware routing (EAR) has gained an increasing popularity in the networking research community. The idea is that traffic demands are redirected over a subset of the network links, allowing other links to sleep to save energy. We studied variant of this problems.

7.1.4.1. Robust Energy-aware Routing with Redundancy Elimination

In [31], we propose GreenRE – a new EAR model with the support of data redundancy elimination (RE). This technique, enabled within routers, can virtually increase the capacity of network links. Based on real experiments on a Orange Labs platform, we show that performing RE increases the energy consumption for routers. Therefore, it is important to determine which routers should enable RE and which links to put into sleep mode so that the power consumption of the network is minimized. We model the problem as a Mixed Integer Linear Program and propose greedy heuristic algorithms for large networks. Simulations on several network topologies show that the GreenRE model can gain further 37% of energy savings compared to the classical EAR model. In [27], we introduce an extended model of the classical multi-commodity flow problem with compressible flows which is also robust with fluctuation of traffic demand and compression rate. An heuristic built on this model allows for 16-28% extra energy saving.

7.1.4.2. Optimizing IGP Link Weights for Energy-efficiency in Multi-period Traffic Matrices

To guarantee QoS while implementing EAR, 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. In [35], we propose 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.

7.1.4.3. Energy Efficient Content Distribution

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 the network congestion. In [18], we study the impact of using in-network caches and content delivery network (CDN) cooperation on an EAR. We formulate this problem as Energy Efficient Content Distribution, we propose an integer linear program (ILP) and a heuristic algorithm to solve it. The objective of this problem is to find a feasible routing, so that the total energy consumption of the network is minimized while the constraints given by the demands and the link capacity are satisfied. We exhibit for which the range of parameters (size of caches, popularity of content, demand intensity, etc.) it is useful to use caches. 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 about 20% of power in average of all the backbone networks considered.

7.1.5. Routing Theory and Forwarding Index

Motivated by finding the best set of links that should be on for energy efficiency, we study the problem of determining the minimum forwarding index of a graph. The (edge) forwarding index of a graph is the minimum, over all possible routings of all the demands, of the maximum load of an edge. This metric is of a great interest since it captures the notion of global congestion in a precise way: the lesser the forwarding-index, the lesser the congestion. This parameter has been studied for different graph classes in the literature. In [42], we determine, for different numbers of edges, the best spanning graphs of a square grid, namely those with a low forwarding index. In [61], [43], we study the following design question: Given a number e of edges and a number n of vertices, what is the least congested graph that we can construct? and what forwarding-index can we achieve? We answer here these questions for different families of graphs: general graphs, graphs with bounded degree, sparse graphs with a small number of edges by providing constructions, most of them asymptotically optimal. Doing so, we partially answer the practical problem that initially motivated our work: If an operator wants to power only e links of its network, in order to reduce the energy consumption (or wiring cost) of its networks, what should be those links and what performance can be expected?

On the complexity of equal shortest path routing.

Additionally, we studied the complexity of configuring the OSPF-ECMP (for Open Shortest Path First-Equal Cost Multiple Path) protocol. In [32], 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.

7.1.6. Routing in Software Defined Networks (SDN)

Software Defined Networking (SDN) is gaining momentum with the support of major manufacturers. While it brings flexibility in the management of flows within the data center fabric, this flexibility comes at the cost of smaller routing table capacities. In [50], we investigate compression techniques to reduce the forwarding information base (FIB) of SDN switches. We validate our algorithm, called MINNIE, on a real testbed able to emulate a 20 switches fat tree architecture. We demonstrate that even with a small number of clients, the limit in terms of number of rules is reached if no compression is performed, increasing the delay of all new incoming flows. MINNIE, on the other hand, reduces drastically the number of rules that need to be stored with a limited impact on the packet loss rate. We also evaluate the actual switching and reconfiguration times and the delay introduced by the communications with the controller. In parallel, we considered the algorithmic problem of compressing bidimensional routings table with priorities on the rules. We carry out in [40] a study of the problem complexity, providing results of NP-completeness, of Fixed-Parameter Tractability and approximation algorithms. In [44], we then propose green routing schemes performing simultaneously the selection of the routes, the compression of the routing tables, and decide to put in sleep mode unused links. These algorithms are tested on networks from the SNDLib library.

7.1.7. Video Streaming

7.1.7.1. Study of Repair Protocols for Live Video Streaming Distributed Systems

In [41], we study distributed systems for live video streaming. These systems can be of two types: structured and un-structured. In an unstructured system, the diffusion is done opportunistically. The advantage is that it handles churn, that is the arrival and departure of users, which is very high in live streaming systems, in a smooth way. On the opposite, in a structured system, the diffusion of the video is done using explicit diffusion trees. The advantage is that the diffusion is very efficient, but the structure is broken by the churn. In this paper, we propose simple distributed repair protocols to maintain, under churn, the diffusion tree of a structured streaming system. We study these protocols using formal analysis and simulation. In particular, we provide an estimation of the system metrics, bandwidth usage, delay, or number of interruptions of the streaming. Our work shows that structured streaming systems can be efficient and resistant to churn.

7.2. Graph Algorithms

Participants: Nathann Cohen, David Coudert, Frédéric Giroire, Fatima Zahra Moataz, Benjamin Momège, 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. We use graph theory to model various network problems. 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. Many results introduced here are presented in detail in the PhD thesis of F. Z. Moataz [14].

7.2.1. Graph Hyperbolicity

The Gromov hyperbolicity is an important parameter for analyzing complex networks which expresses how the metric structure of a network looks like a tree (the smaller gap the better). It has recently been used to provide bounds on the expected stretch of greedy-routing algorithms in Internet-like graphs, and for various applications in network security, computational biology, the analysis of graph algorithms, and the classification of complex networks.

7.2.1.1. Exact Algorithms for Computing the Gromov Hyperbolicity

The best known theoretical algorithm computing this parameter runs in $O(n^{3.69})$ time, which is prohibitive for large-scale graphs. In [26], we propose an algorithm for determining the hyperbolicity of graphs with tens of thousands of nodes. Its running time depends on the distribution of distances and on the actual value of the hyperbolicity. Although its worst case runtime is $O(n^4)$, it is in practice much faster than previous proposals as observed in our experimentations on benchmark instances. We also propose a heuristic algorithm that can be used on graphs with millions of nodes.

In [37], we provide a more efficient algorithm: although its worst-case complexity remains in $O(n^4)$, in practice it is much faster, allowing, for the first time, the computation of the hyperbolicity of graphs with up to $200,000$ nodes. We experimentally show that our new algorithm drastically outperforms the best previously available algorithms, by analyzing a big dataset of real-world networks. We have also used the new algorithm to compute the hyperbolicity of random graphs generated with the Erdös-Renyi model, the Chung-Lu model, and the Configuration Model.

7.2.1.2. Hyperbolicity of Particular Graph Classes

Topologies for data center networks have been proposed in the literature through various graph classes and operations. A common trait to most existing designs is that they enhance the symmetric properties of the underlying graphs. Indeed, symmetry is a desirable property for interconnection networks because it minimizes congestion problems and it allows each entity to run the same routing protocol. However, despite sharing similarities these topologies all come with their own routing protocol. Recently, generic routing schemes have been introduced which can be implemented for any interconnection networks. The performances of such universal routing schemes are intimately related to the hyperbolicity of the topology. Motivated by the good performances in practice of these new routing schemes, we propose in [56] the first general study of the hyperbolicity of data center interconnection networks. Our findings are disappointingly negative: we prove that the hyperbolicity of most data center topologies scales linearly with their diameter, that it the worst-case possible for hyperbolicity. To obtain these results, we introduce original connection between hyperbolicity and the properties of the endomorphism monoid of a graph. In particular, our results extend to all vertex and edge-transitive graphs. Additional results are obtained for de Bruijn and Kautz graphs, grid-like graphs and networks from the so-called Cayley model.

In [57], we investigate more specifically on the hyperbolicity of bipartite graphs. More precisely, given a bipartite graph $B = (V_0 \cup V_1, E)$ we prove it is enough to consider any one side V_i of the bipartition of B to obtain a close approximate of its hyperbolicity $\delta(B)$ — up to an additive constant 2. We obtain from this result the sharp bounds $\delta(G) - 1 \leq \delta(L(G)) \leq \delta(G) + 1$ and $\delta(G) - 1 \leq \delta(K(G)) \leq \delta(G) + 1$ for every graph G, with $L(G)$ and $K(G)$ being respectively the line graph and the clique graph of G. Finally, promising extensions of our techniques to a broader class of intersection graphs are discussed and illustrated with the case of the biclique graph $BK(G)$, for which we prove $(\delta(G) - 3)/2 \leq \delta(BK(G)) \leq (\delta(G) + 3)/2$.

7.2.2. Tree-decompositions

We study the computational complexity of different variants of tree-decompositions. We also study their relationship with various pursuit-evasion games.

7.2.2.1. Diameter of Minimal Separators in Graphs (structure vs metric in graphs)

In [39], 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.

7.2.2.2. Minimum Size Tree-decompositions

Tree-decompositions are the cornerstone 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 is dominated by the size (number of bags) of the tree-decompositions. It is then interesting to minimize the size of the tree-decompositions. In [48], [14], we consider the problem of computing a tree-decomposition of a graph with width at most k and minimum size. We prove that the problem is NP-complete for any fixed $k \geq 4$ and polynomial for $k \leq 2$; for $k = 3$, we show that it is polynomial in the class of trees and 2-connected outerplanar graphs.

7.2.2.3. Non-deterministic Graph Searching in Trees

Non-deterministic graph searching was introduced by Fomin et al. to provide a unified approach for pathwidth, treewidth, and their interpretations in terms of graph searching games. Given $q \geq 0$, the q-limited search number, $s_q(G)$, of a graph G is the smallest number of searchers required to capture an invisible fugitive in G, when the searchers are allowed to know the position of the fugitive at most q times. The search parameter $s_0(G)$ corresponds to the pathwidth of a graph G, and $s_\infty(G)$ to its treewidth. Determining $s_q(G)$ is NP-complete for any fixed $q \geq 0$ in general graphs and $s_0(T)$ can be computed in linear time in trees, however the complexity of the problem on trees has been unknown for any $q > 0$. We introduce in [16] a new variant of graph searching called restricted non-deterministic. The corresponding parameter is denoted by rs_q and is shown to be equal to the non-deterministic graph searching parameter s_q for $q = 0, 1$, and at most twice s_q for any $q \geq 2$ (for any graph G). Our main result is a polynomial time algorithm that computes $rs_q(T)$ for any tree T and any $q \geq 0$. This provides a 2-approximation of $s_q(T)$ for any tree T , and shows that the decision problem associated to s_1 is polynomial in the class of trees. Our proofs are based on a new decomposition technique for trees which might be of independent interest.

7.2.2.4. k-Chordal Graphs: from Cops and Robber to Compact Routing via Treewidth

Cops and robber games, introduced by Winkler and Nowakowski and independently defined by Quilliot, concern a team of cops that must capture a robber moving in a graph. We consider in [34] the class of k-chordal graphs, i.e., graphs with no induced (chordless) cycle of length greater than k, $k \geq 3$. We prove that $k-1$ cops are always sufficient to capture a robber in k-chordal graphs. This leads us to our main result, a new structural decomposition for a graph class including k-chordal graphs. We present a polynomial-time algorithm that, given a graph G and $k \geq 3$, either returns an induced cycle larger than k in G, or computes a tree-decomposition of G, each bag of which contains a dominating path with at most $k-1$ vertices. This allows us to prove that any k-chordal graph with maximum degree Δ has treewidth at most $(k-1)(\Delta-1) + 2$, improving the $O(\Delta(\Delta-1)k-3)$ bound of Bodlaender and Thilikos (1997). Moreover, any graph admitting such a tree-decomposition has small hyperbolicity. As an application, for any n-vertex graph admitting such a tree-decomposition, we propose a compact routing scheme using routing tables, addresses and headers of size $O(k \log \Delta + \log n)$ bits and achieving an additive stretch of $O(k \log \Delta)$. As far as we know, this is the first routing scheme with $O(k \log \Delta + \log n)$-routing tables and small additive stretch for k-chordal graphs.

7.2.2.5. Connected Surveillance Game

The surveillance game [68] models the problem of web-page prefetching as a pursuit evasion game played on a graph. This two-player game is played turn-by-turn. The first player, called the observer, can mark a fixed amount of vertices at each turn. The second one controls a surfer that stands at vertices of the graph and can slide along edges. The surfer starts at some initially marked vertex of the graph, its objective is to reach an unmarked node before all nodes of the graph are marked. The surveillance number $sn(G)$ of a graph G is the minimum amount of nodes that the observer has to mark at each turn ensuring it wins against any surfer in G. Fomin et al. also defined the connected surveillance game where the observer must ensure that marked nodes always induce a connected subgraph. They ask what is the cost of connectivity, i.e., is there a constant $c > 0$ such that the ratio between the connected surveillance number $csn(G)$ and $sn(G)$ is at most c for any graph G. It is straightforward to show that $csn(G) \leq \Delta sn(G)$ for any graph G with maximum degree Δ. Moreover, it has been shown that there are graphs G for which $csn(G) = sn(G) + 1$. In [30], we investigate the question of the cost of the connectivity. We first provide new non-trivial upper and lower bounds for the cost of connectivity in the surveillance game. More precisely, we present a family of graphs G such that $csn(G) > sn(G) + 1$. Moreover, we prove that $csn(G) \leq \sqrt{sn(G)n}$ for any n-node graph G. While the gap between these bounds remains huge, it seems difficult to reduce it. We then define the online surveillance game where the observer has no a priori knowledge of the graph topology and discovers it little-by-little. This variant, which fits better the prefetching motivation, is a restriction of the connected variant. Unfortunately, we show that no algorithm for solving the online surveillance game has competitive ratio better than $\Omega(\Delta)$. That is, while interesting, this variant does not help to obtain better upper bounds for the connected variant. We finally answer an open question [68] by proving that deciding if the surveillance number of a digraph with maximum degree 6 is at most 2 is NP-hard.

7.2.3. Distributed Algorithms

7.2.3.1. Allowing each Node to Communicate only once in a Distributed System: Shared Whiteboard Models

In [21] we study distributed algorithms on massive graphs where links represent a particular relationship between nodes (for instance, nodes may represent phone numbers and links may indicate telephone calls). Since such graphs are massive they need to be processed in a distributed way. When computing graph-theoretic properties, nodes become natural units for distributed computation. Links do not necessarily represent communication channels between the computing units and therefore do not restrict the communication flow. Our goal is to model and analyze the computational power of such distributed systems where one computing unit is assigned to each node. Communication takes place on a whiteboard where each node is allowed to write at most one message. Every node can read the contents of the whiteboard and, when activated, can write one small message based on its local knowledge. When the protocol terminates its output is computed from the final contents of the whiteboard. We describe four synchronization models for accessing the whiteboard. We show that message size and synchronization power constitute two orthogonal hierarchies for these systems.We exhibit problems that separate these models, i.e., that can be solved in one model but not in a weaker one, even with increased message size. These problems are related to maximal independent set and connectivity. We also exhibit problems that require a given message size independently of the synchronization model.

7.2.3.2. Computing on Rings by Oblivious Robots: a Unified Approach for Different Tasks

A set of autonomous robots have to collaborate in order to accomplish a common task in a ring-topology where neither nodes nor edges are labeled (that is, the ring is anonymous). In [36], we present a unified approach to solve three important problems: the exclusive perpetual exploration, the exclusive perpetual clearing, and the gathering problems. In the first problem, each robot aims at visiting each node infinitely often while avoiding that two robots occupy a same node (exclusivity property); in exclusive perpetual clearing (also known as searching), the team of robots aims at clearing the whole ring infinitely often (an edge is cleared if it is traversed by a robot or if both its endpoints are occupied); and in the gathering problem, all robots must eventually occupy the same node. We investigate these tasks in the Look-Compute-Move model where the robots cannot communicate but can perceive the positions of other robots. Each robot is equipped with visibility sensors and motion actuators, and it operates in asynchronous cycles. In each cycle, a robot takes a snapshot of the current global configuration (Look), then, based on the perceived configuration, takes a decision to stay idle or to move to one of its adjacent nodes (Compute), and in the latter case it eventually moves to this neighbor (Move). Moreover, robots are endowed with very weak capabilities. Namely, they are anonymous, asynchronous, oblivious, uniform (execute the same algorithm) and have no common sense of orientation. In this setting, we devise algorithms that, starting from an exclusive and rigid (i.e. aperiodic and asymmetric) configuration, solve the three above problems in anonymous ring-topologies.

7.2.4. Miscellaneous

7.2.4.1. Finding Paths in Grids with Forbidden Transitions

A transition in a graph is a pair of adjacent edges. Given a graph $G = (V, E)$, a set of forbidden transitions $F \subseteq E \times E$ and two vertices $s, t \in V$, we study in [64], [45], [46], [14] the problem of finding a path from s to t which uses none of the forbidden transitions of F. This means that it is forbidden for the path to consecutively use two edges forming a pair in F. The study of this problem is motivated by routing in road networks in which forbidden transitions are associated to prohibited turns as well as routing in optical networks with asymmetric nodes, which are nodes where a signal on an ingress port can only reach a subset of egress ports. If the path is not required to be elementary, the problem can be solved in polynomial time. On the other side, if the path has to be elementary, the problem is known to be NP-complete in general graphs [69]. In [45], we study the problem of finding an elementary path avoiding forbidden transitions in planar graphs. We prove that the problem is NP-complete in planar graphs and particularly in grids. In addition, we show that the problem can be solved in polynomial time in graphs with bounded treewidth. More precisely, we show that there is an algorithm which solves the problem in time $O((3\Delta(k + 1))2k + 4n))$ in n-node graphs with treewidth at most k and maximum degree Δ.

7.3. Graph theory

Participants: Nathann Cohen, Frédéric Havet.

7.3.1. Graph Colouring

7.3.1.1. Steinberg-like Theorems for Backbone Colouring

Motivated by some channel assignment problem, we study the following variation of graph colouring problem. A function $f : V(G) \to \{1, \cdots, k\}$ is a (proper) k-colouring of G if $|f(u) - f(v)| \geq 1$, for every edge $uv \in E(G)$. The chromatic number $\chi(G)$ is the smallest integer k for which there exists a proper k-colouring of G. Given a graph G and a subgraph H of G, a circular q-backbone k-colouring c of (G, H) is a k-colouring of G such that $q \leq |c(u) - c(v)| \leq k - q$, for each edge $uv \in E(H)$. The circular q-backbone chromatic number of a graph pair (G, H), denoted $CBC_q(G, H)$, is the minimum k such that (G, H) admits a circular q-backbone k-colouring. In [19], we first show that if G is a planar graph containing no cycle on 4 or 5 vertices and $H \subseteq G$ is a forest, then $CBC_2(G, H) \leq 7$. Then, we prove that if $H \subseteq G$ is a forest whose connected components are paths, then $CBC_2(G, H) \leq 6$.

7.3.1.2. Complexity of Greedy Edge-colouring

The Grundy index of a graph $G = (V, E)$ is the greatest number of colours that the greedy edge-colouring algorithm can use on G. In [33], we prove that the problem of determining the Grundy index of a graph $G = (V, E)$ is NP-hard for general graphs. We also show that this problem is polynomial-time solvable for caterpillars. More specifically, we prove that the Grundy index of a caterpillar is $\Delta(G)$ or $\Delta(G) + 1$ and present a polynomial-time algorithm to determine it exactly.

7.3.1.3. Proper Orientation Number

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 $\overrightarrow{\chi}(G)$, is the minimum of the maximum indegree over all its proper orientations. It is well-known that $\chi(G) \leq \overrightarrow{\chi}(G) + 1 \leq \Delta(G) + 1$, for every graph G, where $\chi(G)$ and $\Delta(G)$ denotes the chromatic number and the maximum degree of G. In other words, the proper orientation number (plus one) is an upper bound on the chromatic number which is tighter than the maximum degree.

In [17], we ask whether the proper orientation number is really a more accurate bound than the maximum degree in the following sense : does there exists a positive ϵ and such that $\overrightarrow{\chi}(G) \leq \epsilon \cdot \chi(G) + (1 - \epsilon)\Delta(G)$. As an evidence to this, we prove that if G is bipartite (i.e. $\chi(G) \leq 2$) then $\overrightarrow{\chi}(G) \leq \left(\Delta(G) + \sqrt{\Delta(G)}\right)/2 + 1$.

However, the proper orientation number has the drawback to be difficult to compute. We prove in [17] that deciding whether $\overrightarrow{\chi}(G) \leq \Delta(G) - 1$ 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 $\overrightarrow{\chi}(G) \leq 2$, for planar *subcubic* graphs G. Moreover, we prove that it is NP-complete to decide whether $\overrightarrow{\chi}(G) \leq 3$, for planar bipartite graphs G with maximum degree 5.

Nevertheless, it might be interesting to bound the proper orientation number on some graph families. In particular, if we prove that for a graph with treewidth at most t, the proper orientation number is bounded by a function of t, this would imply that finding the proper orientation number of a graph with bounded treewidth is polynomial-time solvable. In [17] we prove $\overrightarrow{\chi}(G) \leq 4$ if G is a tree (or equivalently a graph with treewidth at most 1). In [53], we study the cacti which is a special class of graphs with treewidth at most 2. We prove that $\overrightarrow{\chi}(G) \leq 7$ for every cactus. We also prove that the bound 7 is tight by showing a cactus having no proper orientation with maximum indegree less than 7. We also prove that any planar claw-free graph has a proper orientation with maximum indegree at most 6 and that this bound can also be attained.

7.3.2. Subdivisions of Digraphs

An important result in the Roberston and Seymour minor theory is the polynomial-time algorithm to solve the so-called Linkage Problem. This implies in particular, that for any fixed graph H, deciding whether a graph G contains a subdivision of H as a subgraph can be solved in polynomial time.

We consider the directed analogue F-subdivision problem, which is an analogue for directed graphs (i.e. digraphs). Given a directed graph D, does it contain a subdivision of a prescribed digraph F? In [20], we give a number of examples of polynomial instances, several NP-completeness proofs as well as a number of conjectures and open problems. In [62], we give further support to several open conjectures and speculations about algorithmic complexity of finding F-subdivisions. In particular, up to 5 exceptions, we completely classify for which 4-vertex digraphs F, the F-subdivision problem is polynomial-time solvable and for which it is NP-complete. While all NP-hardness proofs are made by reduction from some version of the 2-linkage problem in digraphs, some of the polynomial-time solvable cases involve relatively complicated algorithms.

7.4. Applications to Other Domains

Participants: Christelle Caillouet, David Coudert, Nicolas Nisse.

7.4.1. Unveiling Contacts within Macro-molecular assemblies by solving Minimum Weight Connectivity Inference Problems

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 in finding the most plausible contacts between these subunits, and minimum connectivity inference (MCI) is the variant consisting in 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 [15] two novel algorithms, MILP-W and 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 three systems (yeast exosome, yeast proteasome lid, human eiF3), for which reference contacts are known (crystal structure, cryo electron microscopy, cross-linking), show that our algorithms predict contacts with high specificity and sensitivity, yielding a very significant improvement over previous work, typically a twofold increase in sensitivity. The software accompanying this paper is made available, and should prove of ubiquitous interest whenever connectivity inference from oligomers is faced.

7.4.2. Recovery of Disrupted Airline Operations using k-Maximum Matching in Graphs

When an aircraft is approaching an airport, it gets a short time interval (called *slot*) that it can use to land. If the landing of the aircraft is delayed (because of bad weather, or if it arrives late, or if other aircrafts have to land first), it loses its slot and Air traffic controllers have to assign it a new slot. However, slots for landing are a scarce resource of the airports and, to avoid that an aircraft waits too much time, Air traffic controllers have to regularly modify the assignment of the slots of the aircrafts. Unfortunately, for legal and economical reasons, Air traffic controllers can modify the slot-assignment only using two kind of operations: either assign to aircraft A a slot that was free, or give to A the slot of another aircraft B and assign to B a free slot. The problem is then the following. Let $k \geq 1$ be an odd integer and let G be a graph and M be a matching (set of pairwise disjoint edges) of G. What is the maximum size of a matching that can be obtained from M by using only augmenting paths of length at most k? Moreover, how to compute such a maximum matching? This problem has already been studied in the context of wireless networks, mainly because it provides a simple approximation for the classical matching problem. We prove in [65], [49] that this problem can be solved in polynomial-time when $k \leq 3$. Then, we show that, for any odd integer $k \geq 5$, the problem is NP-complete in planar bipartite graphs with maximum degree at most 3.

7.4.3. Inference of Curvilinear Structure based on Learning a Ranking Function and Graph Theory

To detect curvilinear structures in natural images, we propose in [63] a novel ranking learning system and an abstract curvilinear shape inference algorithm based on graph theory. We analyze the curvilinear structures as a set of small line segments. In this work, the rankings of the line segments are exploited to systematize the topological feature of the curvilinear structures. Structured Support Vector Machine is employed to learn the ranking function that predicts the correspondence of the given line segments and the latent curvilinear structures. We first extract curvilinear features using morphological profiles and steerable filtering responses. Also, we propose an orientation-aware feature descriptor and a feature grouping operator to improve the structural integrity during the learning process. To infer the curvilinear structure, we build a graph based on the output rankings of the line segments. We progressively reconstruct the curvilinear structure by looking for paths between remote vertices in the graph. Experimental results show that the proposed algorithm faithfully detects the curvilinear structures within various datasets.

7.4.4. Web Transparency for Complex Targeting: Algorithms, Limits, and Tradeoffs

Big Data promises important societal progress but exacerbates the need for due process and accountability. Companies and institutions can now discriminate between users at an individual level using collected data or past behavior. Worse, today they can do so in near perfect opacity. The nascent field of web transparency aims to develop the tools and methods necessary to reveal how information is used, however today it lacks robust tools that let users and investigators identify targeting using multiple inputs. In [67], [38], we formalize for the first time the problem of detecting and identifying targeting on combinations of inputs and provide the first algorithm that is asymptotically exact. This algorithm is designed to serve as a theoretical foundational block to build future scalable and robust web transparency tools. It offers three key properties. First, our algorithm is service agnostic and applies to a variety of settings under a broad set of assumptions. Second, our algorithm's analysis delineates a theoretical detection limit that characterizes which forms of targeting can be distinguished from noise and which cannot. Third, our algorithm establishes fundamental tradeoffs that lead the way to new metrics for the science of web transparency. Understanding the tradeoff between effective targeting and targeting concealment lets us determine under which conditions predatory targeting can be made unprofitable by transparency tools.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Amadeus

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

Duration: May 2014 - April 2015

Inria teams: COATI, SCALE

Abstract: This collaboration aims at assessing 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.

8.2. Bilateral Grants with Industry

8.2.1. Contract CIFRE with KONTRON

Participants: Michel Syska, Mohamed Amine Bergach.

We have contracted with KONTRON (worldwide company which designs and manufactures embedded systems) a "Convention de recherche encadrant une bourse CIFRE" on the topic *Graphic Processing Units for Signal Processing*, which work is a joint supervision with AOSTE project.

Duration: November 2011 - April 2015

8.2.2. ADR Network Science, joint laboratory Inria / Alcatel-Lucent Bell-labs France

Participants: David Coudert, 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.).

Duration: January 2013 - December 2015

8.2.3. Allocation Carnot Inria / Instant System

Participants: David Coudert, Idriss Hassine.

The Instant System startup company develop a platform in the area of Intelligent transportation systems (ITS). The partnership with COATI aims at designing algorithms for itinerary planning in multimodal transportation networks. The main objective is to combine public transport system and dynamic car-pooling.

Duration: December 2015 - November 2016 (12 man-month)

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

9.1.1.1. ANR Blanc STINT, 2014-2017

Participants: Pierre Aboulker, Jean-Claude Bermond, David Coudert, Frédéric Havet, Luc Hogie, William Lochet, Nicolas Nisse, Stéphane Pérennes, Michel Syska.

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

The aim of STINT is to answer the following fundamental question: *given a (possibly infinite) family ψ of graphs, what properties 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/)

9.1.2. PEPS

9.1.2.1. PEPS MoMis SYSTEMIC, 2015

Participant: Frédéric Giroire.

The SYSTEMIC project was led by COATI and involves the LAMA (Paris Est), GREDEG (Sophia Antipolis) and CREM (Rennes) laboratories.

The aim of SYSTEMIC was to bring together the expertises of researchers in economics, graph theory and financial mathematics to propose new models to evaluate the systemic risk of networks of financial institutions, and to propose new methods to mitigate the risk of contagions in such networks. The novelty of the project was in particular to consider strategies for a dynamic control of heterogeneous networks.

9.1.3. GDR Actions

9.1.3.1. Action ResCom, ongoing (since 2006)

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

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

9.1.3.2. Action Graphes, ongoing (since 2006)

Action Graphes, working group of GDR IM, CNRS.

(http://gtgraphes.labri.fr/)

9.2. European Initiatives

9.2.1. Collaborations with Major European Organizations

AOR (Vassilis Zissimopoulos) : University of Athens, Department of Informatics and Telecommunications (Greece)

Combinatorial Optimization, Games and Applications (COGA), June 2015- September 2016

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

9.3. International Initiatives

9.3.1. Inria International Labs

Inria Chile
Associate Team involved in the International Lab:

9.3.1.1. 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: https://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.

9.3.2. Inria International Partners

9.3.2.1. Informal International Partners

Apart from formal collaboration COATI members maintain strong connections with the following international teams, with regular visits of both sides.

Univ. of Southern Denmark, Prof. Jorgen Bang Jensen

RWTH Aachen Univ., Lehrstuhl II für Mathematik, Germany, Prof. Arie M.C.A. Koster

Concordia Univ. - Montréal, Quebec, Canada, Prof. Brigitte Jaumard

9.3.3. 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 Ceará, Brasil, 2014-2016.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

Jorgen Bang Jensen : Jan 31 - June 13, Univ. of Southern Denmark

Sylvain Leguay : Feb 2 - March 27, Univ. Paris XI, LRI, Orsay, France

Mauricio Abel Soto Gomez : Feb 23 - March 20, Univ. Adolfo Ibáñez, Santiago, Chile

Takako Kodate : March 23 - Apr 4, Tokyo Woman's Christian Univ., Japan

Min-Li (Joseph) Yu : March 3 - Apr 8, Univ. of the Fraser valley, Abbotsford, (BC), Canada

Medji Kaddour : May 4 - 15, Univ. d'Oran, Algérie

Nicolas De Almeida Martins : May 20 - July 30, Univ. Federal do Ceará, Fortaleza, Brazil

Samuel Nascimiento de Araujo : June - July, Univ. Federal do Ceará, Fortaleza, Brazil

Esteban H. Roman Catafau : Oct 1 - 10, Univ. Adolfo Ibáñez, Santiago, Chile

Arunabha Sen : Oct 12 - 17, Arizona State Univ., USA

Fabricio Benevides : Oct 19 - 31, Univ. Federal do Ceará, Fortaleza, Brazil

Victor Campos : Oct 19 - 31, Univ. Federal do Ceará, Fortaleza, Brazil

Eduardo Moreno : Nov 1 - 7, Univ. Adolfo Ibáñez, Santiago, Chile

9.4.2. Visits to International Teams

9.4.2.1. Research stays abroad

David Coudert

- Univ. Adolfo Ibañez and Univ. Chile, Santiago, Chile, in the context of Inria associated team AlDyNet, April 3-19 and November 21-December 5, 2015;
- Department of Information Engineering at University of Florence, Italy, June 23-30, 2015;
- Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens, Greece, September 7-11, 2015.

Guillaume Ducoffe

- Univ. Adolfo Ibañez and Univ. Chile, Santiago, Chile, in the context of Inria associated team AlDyNet, November 21-December 6, 2015.

Frédéric Giroire

- Univ. Adolfo Ibañez and Univ. Chile, Santiago, Chile, in the context of Inria associated team AlDyNet, November 13-29, 2015.

Frédéric Havet

- Univ. Federal do Ceará, Fortaleza, Brazil, May 5-10, 2015;
- Univ. Orléans - LIFO, July 6-10 2015.

Nicolas Nisse

- Univ. Federal do Ceará, Fortaleza, Brazil, May 4-17, 2015;
- Univ. Aix-Marseille, June 29-July 2015;

Univ. Adolfo Ibañez and Univ. Chile, Santiago, Chile, in the context of Inria associated team AlDyNet, November 13-29, 2015.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

Jean-Claude Bermond :

Mediterranean Days 2015 : February 18-20 (http://campus.sophiatech.fr/meddays2015/).

Frédéric Havet :

SGT 2015 : 2nd French School on Graph Theory, Porquerolles, France, May 18-22 2015;

15th JCALM : 15th Journées Combinatoire et Algorithmes du Littoral Méditerranéen. Sophia Antipolis, France, March 10-11, 2015.

Nicolas Nisse :

GRASTA-MAC : joint Workshops 7th Workshop on GRAph Searching, Theory and Applications and 5th workshop on Moving And Computing, Montréal, Canada, October 19-23rd, 2015. Organizers: G. Hahn and N. Nisse.

10.1.1.2. Member of the organizing committees

David Coudert, Frédéric Havet (chair), Michel Syska : SGT 2015, 2nd French School on Graph Theory, Porquerolles, France, May 18-22 2015;

Frédéric Havet (chair) : 17th Journées Graphes et Algorithmes (JGA 2015), Orléans, France, November 4-6, 2015.

10.1.2. Scientific events selection

10.1.2.1. Chair of conference program committees

Frédéric Giroire

Algotel'15: 17es Rencontres Francophones sur les Aspects Algorithmiques de Télécommunications, Beaune, France, June 2-5, 2015; Chairs: L. Blin and F. Giroire.

10.1.2.2. Member of the conference program committees

David Coudert :

ONDM'15 : 19th International Conference on Optical Networking Design and Modeling, Pisa, Italy, May 11-14, 2015;

PHYSComNet : International Workshop on Physics Inspired Paradigms in Wireless Communications and Networks, Bombay, India, May 29, 2015;

IEEE ICC'15 : IEEE International Conference on Communications, London, UK, June 8-12, 2015;

SEA'15 : 14th International Symposium on Experimental Algorithms, Paris, France, June 29 - July 1, 2015;

USRR'15 : 3rd International Workshop on Understanding the Inter-play between Sustainability, Resilience and Robustness in networks, Munich, Germany, October 7, 2015;

IEEE Globecom'15 : IEEE Global Communications Conference, San Diego, CA, USA, December 6-10, 2015.

Nicolas Nisse :

International Conference on Ad Hoc Networks and Wireless (Ad-Hoc Now), track on Mobile Agents, Athens, Greece (June 29-July 1st 2015).

VIII Latin-American Algorithms, Graphs and Optimization Symposium (LAGOS), Praia das Fontes, Beberibe, Ceará, Brazil (11-15 May, 2015).

10.1.3. Journal

10.1.3.1. Member of the editorial boards

Jean-Claude Bermond :

Combinatorics Probability and Computing (Cambridge University Press);

Computer Science Reviews (Elsevier);

Discrete Applied Mathematics (Elsevier);

Discrete Mathematics (ScienceDirect);

Discrete Mathematics, Algorithms and Applications (World Scientific);

Journal of Graph Theory (Wiley);

Journal of Interconnection Networks (Advisory Board, World Scientific);

Mathématiques et Sciences Humaines (http://msh.revues.org);

Networks (Wiley);

Parallel Processing Letters (World Scientific);

SIAM's Discrete Mathematics and Applications Book Series (SIAM).

David Coudert :

Discrete Applied Mathematics (Elsevier);

Networks (Wiley).

Frédéric Havet :

Discrete Mathematics and Theoretical Computer Science (http://dmtcs.episciences.org/).

10.1.3.2. Reviewer - Reviewing activities

Members of COATI have reviewed numerous manuscripts submitted to international journals, including: Algorithmica, Bulletin of the Malaysian Mathematical Sciences Society, Computer Communications, Computer Networks, Computers & Operations Research, Discrete Applied Mathematics, IEEE/OSA Journal of Lightwave Technology, Networks, Photonic Network Communications, The Computer Journal, Theoretical Computer Science, IEEE/ACM Transactions on Communications, IEEE/ACM Transactions on Networking, etc

10.1.4. Invited talks

Frédéric Havet :

VIII Latin-American Algorithms, Graphs and Optimization Symposium (LAGOS 2015), Beberibe, Brazil (May 11-15, 2015), "Induced subdigraphs of digraphs with large chromatic number";

2015 Barbados Graph Theory Workshop, Holetown, Barbados (March 27-April 3), "Subdigraphs of digraphs with large chromatic number".

Nicolas Nisse :

Journées du GDR IM, Bordeaux (Feb. 2nd, 2015), "Cops and robber games in graphs";

Réunion ANR Displexity, Arcachon (September 3rd, 2015), "Allowing each node to communicate only once in a distributed system";

GRASTA-MAC'15, Montréal, Canada (October 19th, 2015), "Cops and Robber Games";

Journées Graphes et Algorithmes (JGA) 2015, Orléans (November 4th, 2015), "Jeux de Gendarmes et Voleur dans les Graphes".

10.1.5. Leadership within the scientific community

David Coudert :

Member of the steering committee of *Pôle ResCom du GDR RSD du CNRS* (since 2005);

Member of the steering committee of *Rencontres francophones sur les aspects algorithmiques des télécommunications* (AlgoTel).

Frédéric Giroire :

Member of the steering committee of *Action GREEN du GDR RSD du CNRS*.

Frédéric Havet :

Member of the steering committee of GT Graphes du GDR IM du CNRS;

Member of the steering committee of Journées Graphes et Algorithmes (JGA);

Member of the steering committee of Journée Combinatoire et Algorithmes du Littoral Méditerranéen (JCALM).

10.1.6. Scientific expertise

Jean-Claude Bermond :

Expert for DRTT-MESR (Crédit Impôt Recherche CIR);

Expert for an Eurostars application POF transceiver;

Evaluation of PISCOPIA Fellowship Programme Marie Curie Action, for the University of Padua (Italia).

Christelle Caillouet :

Member of the comité de sélection MCF of 27^{e} section of Univ. Nice Sophia Antipolis;

Member of the comité de sélection MCF of 27^{e} section of Univ. Toulon.

David Coudert :

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

Member of the comité de sélection MCF of 27^{e} section of LIRMM, Univ. Montpellier.

Frédéric Havet :

Expert for the ANR.

Joanna Moulierac :

Member of the comité de sélection MCF of 27^{e} section of Univ. Nice Sophia Antipolis.

Nicolas Nisse :

Expert for the ANR.

Michel Syska :

Expert for DRTT PACA.

10.1.7. Research administration

Jean-Claude Bermond :

Member of the doctoral school of the Univ. of Marseille;

Responsible of the Attractivity for Inria Sophia Antipolis - Méditerranée and more generally for the Campus Sophia Tech (in particular signature of bilateral agreements, contacts with French Embassies and creation of join grants).

Frédéric Giroire :

Elected member of I3S laboratory committee since 2012.

Frédéric Havet :

Responsible of Pôle ComRed of I3S laboratory.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

The members of COATI are strongly involved in teaching with more than 1200 hours in various university levels.

Licence

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

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

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

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

Guillaume Ducoffe, *Introduction au Web*, 39h ETD, L2, Polytech'Nice, Univ. Nice Sophia Antipolis (UNS), France;

Guillaume Ducoffe, *Programmation Objet*, 25.5h ETD, L2, Polytech'Nice, UNS, France;

Guillaume Ducoffe, *Algorithmique et Structures de Données*, 39h ETD, L2, Polytech'Nice, UNS, France;

Nicolas Huin, *Networks*, 42h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Alvinice Kodjo, *Interfaces Homme Machine*, 24h ETD, Level L1, UNS;

Alvinice Kodjo, *Réseaux*, 15h ETD, Level L2, UNS;

Dimitris Letsios *Algorithmique et Programmation Impérative*, 36h ETD, Level L1, UNS;

Dimitris Letsios *Programmation Web*, 8h ETD, Level L1, UNS;

Dimitris Letsios *Informatique Fondamentale*, 36h ETD, Level L1, UNS;

Dimitris Letsios *Algorithmique et Programmation Objet*, 54h ETD, Level L2, UNS;

Dimitris Letsios *Programmation Orientée Objet Java*, 18h ETD, Level L2, UNS;

Dimitris Letsios *Mathématiques*, 18h ETD, Level L3, UNS;

Dimitris Letsios *Mathématiques*, 18h ETD, Level M1, UNS;

Fatima Zahra Moataz, *Programmation avec Python*, 12h ETD, Level L1, UNS;

Fatima Zahra Moataz, *Systèmes Informatiques*, 24h ETD, Level L1, UNS;

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

Joanna Moulierac, *Introduction to Operating Systems*, 60h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

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

Joanna Moulierac, *Algorithmics*, 60h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Nicolas Nisse, *Introduction à l'informatique*, 24h ETD, Classe préparatoire MPSI (Lycée international de Valbonne), France;

Michel Syska, *Operating Systems : Advanced Programming*, 90h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Algorithmics*, 90h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Distributed Programming*, 30h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

Michel Syska, *Bash Scripting*, 40h ETD, Level L3, IUT Nice Côte d'Azur, UNS;

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

Michel Syska, *Linux System 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, UNS;

Frédéric Giroire, *Green Networks*, 18h ETD, stream UbiNet of Master 2 IFI, UNS;

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

Frédéric Havet, *Combinatorial optimisation*, 24h ETD, M1 international, UNS, France;

Nicolas Nisse, *Resolution Methods*, 15h ETD, M1 international, UNS, France;

Nicolas Nisse, *Graph Algorithms*, 18h ETD, M2 IFI, parcours UBINET, UNS, France.

Doctorate

Nicolas Nisse, *Graph Theory and Optimization*, 27h ETD, University of Oulu, Finland, September 15-18th, 2015.

10.2.2. Internships

Paul Bertot : Nov 2014 - Feb 2015, IUT Nice Côte d'Azur, France

Flavian Jacquot : Nov 2014 - Feb 2015, IUT Nice Côte d'Azur, France

Bogdan Sirenko : March - Aug 2015, Master IFI, Ubinet, Univ. of Nice, France

Theodoros Karagkioules : Oct 2015 - March 2016, National and Kapodistrian Univ. of Athens, Greece

Konstantinos Priftis : Oct 2015 - March 2016, Univ. of Patras, Greece

Steven Roumajon : March - Aug 2015, Master RIF, Univ. of Nice, France

10.2.3. Teaching Administration

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, responsible of teh recruiting committee and of the winter school.

IUT Nice Côte d'Azur

Christelle Molle-Caillouet, Co-Responsible of QLIO Department, since September 2015;

Joanna Moulierac, Co-Responsible of the DUT Informatique en Alternance, Computer Science Department, since January 2014;

Joanna Moulierac, member of the Conseil de D épartement Informatique at IUT Nice.

10.2.4. Supervision

PhD : Fatima Zahra Moataz, *Towards Efficient and Fault-Tolerant Optical Networks: Complexity and Algorithms* [14], Université Nice Sophia Antipolis, October 30, 2015. Supervisor : David Coudert;

PhD : Mohamed Amine Bergach, *Adaptation of the Fast Fourier Transform processing on hybrid integrated CPU/GPU architecture* [13], Université Nice Sophia Antipolis, October 2, 2015. Supervisors : Robert de Simone (AOSTE) and Michel Syska;

PhD in progress : Steven Roumajon, *Regional competitiveness and innovation networks*, since November 2015. Supervisors : Frédéric Giroire and Patrick Musso (GREDEG);

PhD in progress : Nicolas Huin, *Energy-Efficient Software Defined Networks*, since October 2014. Supervisors : Frédéric Giroire and Dino Lopez (I3S);

PhD in progress : Guillaume Ducoffe, *Metric properties of large graphs*, since September 2014. Supervisor : David Coudert;

PhD in progress : William Lochet, *Cliques and independent sets in graph classes, generalisation to the oriented case*, since September 2015, co-supervised by Frédéric Havet and Stéphan Thomassé (ENS Lyon).

10.2.5. Juries

Jean-Claude Bermond :

Member of the PhD jury of Fatima Zahra Moataz, Univ. Nice Sophia Antipolis, October 30, 2015.

David Coudert :

Member of the PhD jury of Fatima Zahra Moataz, Univ. Nice Sophia Antipolis, October 30, 2015;

Referee and member of the PhD jury of Benjamin Momège, Univ. Blaise Pascal, Clermont-Ferrand, July 8, 2015.

Frédéric Havet :

Referee and member of the PhD jury of M. Bonamy, Univ. of Montpellier, February 9 2015;

Referee and member of the PhD jury of R. Letourneur, Université of Orléans, July 9 2015;

Member of the PhD jury of Hang Zhou, ENS Paris, July 6 2015.

Michel Syska :

Member of the PhD jury of Mohamed Amine Bergach, Univ. Nice Sophia Antipolis, October 02, 2015.

10.3. Popularization

- Vulgarization talk : N. Nisse presented a talk on "Combinatorial Games", Lycée des Remparts (classes de seconde), Marseille (April 17th, 2015).
- Fête de la Science : F. Havet presented the stand "Pavage, art et preuves" et "Magie mathématique" at Vinon-sur-Verdon, France (October 12-16, 2015); F. Havet gave the talk "La science du ballon de football" at Vinon-sur-Verdon, France (October 16, 2015).
- Semaine des Mathématiques : F. Havet presented the stand "Les maths c'est magique" at Mouans Sartoux (March 18, 2015).
- Vendredis de la Science : F. Havet conducted scientific workshops for school children (6-11 year old) on friday afternoon in Rians, France. Once a month in March, April, May, June 2015, and weekly since November 2015.
- Jean-Claude Bermond presented a talk on the impact of big data on the telecommunications services and networks for banks investors at Paris, France (April 10 2015).

11. Bibliography

Major publications by the team in recent years

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Doctoral Dissertations and Habilitation Theses

[13] M. A. BERGACH. *Adaptation of the Fast Fourier Transform processing on hybride integrated CPU/GPU architecture*, Université Nice Sophia Antipolis, October 2015, https://hal.inria.fr/tel-01245958

[14] F. Z. MOATAZ. *Towards efficient and fault-tolerant optical networks : complexity and algorithms*, Université Nice Sophia Antipolis, October 2015, https://tel.archives-ouvertes.fr/tel-01263512

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