INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

# *Project-Team Gang*

# *Graphs, networks and algorithms*

*Paris - Rocquencourt*

THEME COM

Activity Report

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*Gang is a joined team between INRIA, CNRS and Paris Diderot University, through the "laboratoire d'informatique algorithmique, fondements et applications",* LIAFA *(UMR 7089).*

# 1. Team

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# 2. Overall Objectives

## 2.1. Overall Objectives

Our goal is to develop the field of graph algorithms for networks. Based on algorithmic graph theory and graph modeling we want to understand what can be done in these large networks and what cannot. Furthermore, we want to derive practical distributed algorithms from known strong theoretical results. Finally, we want to extract possibly new graph problems by focusing on particular applications.

The main goal to achieve in networks are efficient searching of nodes or data, and efficient content transfers. We propose to implement strong theoretical results in that domain to make significant breakthrough in large network algorithms. These results concern small world routing, low stretch routing in doubling metrics and bounded width classes of graphs. They are detailed in the next section. This implies several challenges:

- testing our target networks against general graph parameters known to bring theoretically tractability,
- implementing strong theoretical results in the dynamic and distributed context of large networks.

A complementary approach consists in studying the combinatorial and graph structures that appear in our target networks. These structures may have inherent characteristics coming from the way the network is formed, or from the design goals of the target application.

# 3. Scientific Foundations

## 3.1. Scientific Foundations

**Keywords:** *doubling metrics*, *graph algorithms*, *network protocols*, *overlay*, *small world*.

### 3.1.1. Structured/Unstructured Overlays

Recent years have brought tremendous progress along the peer-to-peer paradigm allowing large scale decentralized application to be practically deployed. The main achievement of this trend is certainly efficient content distribution through the BitTorrent protocol [14]. The power of peer-to-peer content distribution is to rely on the upload capacity of the node interested in receiving the content. This allows to scale to very large number of participants. The main breakthrough of BitTorrent resides in its “tit for tat” strategy inspired from game theory to give incentive to cooperate. For that purpose, a peer preferentially uploads preferentially offering best reciprocity. This kind of preferences induces an interesting graph structure with ordered neighborhoods. Understanding the dynamic behavior of such affinity graphs is an important for stabilizing the performance of such protocols.

A second major achievement of the peer-to-peer paradigm concerns indexing with distributed hashtables [30], [32], [34]. The idea behind these proposals is to organize the peers into a structure close to well known graphs with low diameter such as hight dimension torus, hypercube or de Bruijn graph. Efficient routing to the node storing a given key is then guaranteed. This academic work has lead to practical basic indexing facilities by introducing redundancy in the structure [29]. This is typically the kind of approach we want to promote: from known efficient theoretical solutions to practical working protocols. We have contributed to this trend by introducing de Bruijn based solutions [23], [24] with redundancy in the contact graph to resist node churn.

### 3.1.2. Small World Phenomenon

Popularized emerging properties include degree distributions observed to be power law in many networks or clustering coefficient observed to be high in social networks or low average distances. This last point gave the denomination of “small worlds” for this type of networks. Some work [10], [35] try to give models that give raise to such statistical properties. In that line, numerous results such as [9] try to derive efficient algorithms based only on these statistical properties. This particular approach tends to concentrate load on nodes with high degrees and may not be suited for applications where nodes have similar capacities. Other interesting work [19] try to explain this statistical observation forms an inherent optimization problem operating when constructing the network.

On the other hand, in its seminal paper [26], Kleinberg focuses on the algorithmic aspects of such social networks and shows how adding random links to a torus can produce efficient greedy routing. This result has been extend to more general classes of graphs [33], [20] such as bounded growth metric graphs [18]. However, this augmentation process is not always feasible [22]. Such theoretical work is particularly interesting for overlay networks where this augmenting process simply consists in opening additional connections.

### 3.1.3. Doubling Metrics

Bounded growth and doubling metrics generalize Euclidean metrics. A metric has bounded growth if the size of any ball increases by a factor not larger than $2^d$ when its radius is doubled [25]. A metric is doubling if any set of diameter $D$ can be covered with at most $2^d$ sets of diameter $D/2$ [11]. In both cases, the smallest acceptable value of $d$ is called the dimension of the metric. The metric of any $d$ dimensional Euclidean space has bounded growth dimension $O(d)$. Any bounded growth metric of dimension $d$ has doubling dimension $O(d)$. The doubling metric is the most general and has the additional property of being inherited by subspaces: the metric induced by a doubling metric on a subset of nodes is also doubling. For example, sampling nodes in an Euclidean space always results in a doubling metric.

As networks are embedded in our usual three dimensional space, it is legitimate to think than some network metrics may be modeled through doubling metrics. Recent results thus investigate network problems for the restricted classes of graphs with bounded growth or doubling metric [33], [8], [25], [27]. However, the doubling nature of large networks such as the Internet has still not be tested.

### 3.1.4. Bounded Width Classes of Graphs

Many graph parameters such as treewidth, branchwidth, rankwidth, cutwidth, cliquewidth ...have been introduced in recent years [31], [16] to measure the structure of a given graph. These parameters are of course

NP-complete to compute, but when it can be proved that for a given class of graphs the parameter is bounded by a constant then it can be proved using graph grammars (see Courcelle's fundamental work) that most of the optimization problems on this class are polynomially tractable, and sometimes we know the existence of a linear algorithm (but the hidden constant can be very high !)

The most famous parameter, namely the treewidth captures the distance of the graph to a tree, and therefore when the treewidth is small a dynamic programming approach can be used [15].

Despite some promising results, applications of these notions has still to be done for networks, in a practical perspective.

# 4. Application Domains

## 4.1. Application Domains

**Keywords:** *Internet*, *large scale ad hoc*, *peer-to-peer applications*, *telecommunications*, *web graph*.

Application domains include evaluating Internet performances, the design of new peer-to-peer applications, enabling large scale ad hoc networks and mapping the web.

- The application of measuring and modeling Internet metrics such as latencies and bandwidth is to provide tools for optimizing Internet applications. This concerns especially large scale applications such as web site mirroring and peer-to-peer applications.
- Peer-to-peer protocols are based on a all equal paradigm that allows to design highly reliable and scalable applications. Besides the file sharing application, peer-to-peer solutions could take over in web content dissemination resistant to high demand bursts or in mobility management. Envisioned peer-to-peer applications include video on demand, streaming, exchange of classified ads,...
- Wifi networks have entered our every day life. However, enabling them at large scale is still a challenge. Algorithmic breakthrough in large ad hoc networks would allow to use them in fast and economic deployment of new radio communication systems.
- The main application of the web graph structure consists in ranking pages. Enabling site level indexing and ranking is a possible application o f such studies.

# 5. Software

## 5.1. Palabre/Peerple : a Cooperative Peer-to-peer Platform

**Participants:** Anh-Tuan Gai [MOVE 'N PLAY Company, Paris, France], Fabrice Le-Fessant [INRIA, Saclay], Laurent Viennot.

The peer-to-peer paradigm can be used to duplicate sensible data. Free disk space can be exchanged to ensure cooperative reliable storage. Anh-Tuan Gai, Fabrice Le-Fessant and Laurent Viennot are developing a peer-to-peer client for personal files sharing and backup. Anh-Tuan Gai, formerly a postdoctoral fellow in the project, has created Move 'N Play company for disseminating this software. Research aspects are still developed in tight collaboration with Fabrice Le Fessant(ASAP).

Peerple is an open-source project http://peerple.gforge.inria.fr/.

Several improvements are forecasted:

- social network based topology
- distributed network services (such as DNS)
- improvement of the backup system for dedicated environments such as universities or companies (where many computers may share the same files).

# 6. New Results

## 6.1. Small world networks structure

**Keywords:** *augmented graphs*, *routing algorithm*, *small world*.

**Participants:** Pierre Fraigniaud, Cyril Gavoille [CNRS LABRI, University of Bordeaux, France], Adrian Kosowski [CNRS LABRI, University of Bordeaux, France], Emmanuelle Lebhar, Zvi Lotker [University of Tel Aviv, Israel].

### *6.1.1. Small world routing*

Following the result that we obtained last year showing that it is not possible to augment any graph by random shortcuts to get a small world behavior, paper [3] tackles the question of *universal* augmentation with relaxed guaranties. Specifically, it was known that any graph can be augmented to achieve $O(\sqrt{n})$-length greedy paths between any pair, and that it is not possible to design a universal augmentation achieving a greedy path length less than $\Omega(n^{1/\sqrt{\log n}})$ between any pair. Our paper breaks the $\sqrt{n}$-barrier by showing that it is possible to design a universal augmentation achieving $O(n^{1/3})$-length greedy path between any pair. This paper obtained the best paper award of the conference SPAA'07.

### *6.1.2. Small world structure*

On the other hand, the paper [3] study the possibility of checking the validity of the augmented graph model. precisely, we show that it is possible to design an algorithm which, given an augmented graph, extracts almost all its random shortcuts, and more interestingly that the base graph that it outputs cannot affect the supposed routing performances of the input graph by more than a poly-logarithmic factor. This question was first asked by Jon Kleinberg in 2006 and this is the first result achieving a partial answer to it, to our knowledge.

## 6.2. Peer-to-Peer

### *6.2.1. Video-on-Demand over Peer-to-Peer networks*

**Keywords:** *Content distribution*, *Matching Algorithms*, *Peer-to-peer (P2P)*, *Video-on-Demand(VoD)*.

**Participants:** Yacine Boufkhad, Fabien Mathieu [France Telecom R&D, Issy Les Moulineaux, France], Fabien de Montgolfier, Diego Perino, Laurent Viennot.

Video on Demand (VoD) is the next challenge in Content Distribution over the Internet. Bandwidth requirements for serving quality content to a large number of customers are very high: VoD operators have to operate a large number of servers with high-speed network links, and other expensive resources. An innovative approach consists in taking advantage of peer-to-peer algorithms. Currently, home Internet bandwidth access is relatively scarce with respect to video playback rate, and thus peers can only alleviate the load of servers, which are still mandatory. However, server-free architectures become possible as the access bandwidth increases, for example by the dint of new technologies such as fiber to the home.

In [6], we analyze a system where $n$ set-top boxes with same upload and storage capacities collaborate to serve $r$ videos simultaneously (a typical value is $r = n$). We give upper and lower bounds on the catalog size of the system, i.e. the maximal number of distinct videos that can be stored in such a system so that any demand of at most $r$ videos can be served. Besides $r/n$, the catalog size is constrained by the storage capacity, the upload capacity, and the maximum number of simultaneous connections a box can open. We show that the achievable catalog size drastically increases when the upload capacity of the boxes becomes strictly greater than the playback rate of videos.

### *6.2.2. Unstructured P2P live streaming*

**Keywords:** *Peer-to-peer (P2P)*, *epidemic*, *live streaming*, *overlay network*.

**Participants:** Thomas Bonald [France Telecom R&D, Issy Les Moulineaux, France], Laurent Massoulie [Thomson R&D, Paris, France], Fabien Mathieu [France Telecom R&D, Issy Les Moulineaux, France], Diego Perino, Andy Twigg [Thomson R&D, Paris, France].

Several peer-to-peer systems for live streaming have been recently deployed (e.g. CoolStreaming, PPLive, SopCast). It turns out they follow an unstructured approach to P2P live streaming where the stream is divided series of pieces (chunks) that are exchanged among peers in order to retrieve the complete sequence and play out the stream. Data exchange is driven by chunk/peer selection algorithms that can be push/pull depending on whether it is the sender or the receiver that does the selection. Moreover, the chunk or the peer can be selected first leading to different system performance.

In [5] we propose several results that contribute to understand performance trade-off of push-based chunk/peer selection algorithms. We prove that random peer-latest useful chunk algorithm can achieve dissemination at an optimal rate and within an optimal delay, up to an additive constant term. By means of simulations we validate the above theoretical result and we compare the performance of various chunk/peer selection algorithms in terms of delay, rate, and control overhead. In particular, we identify several peer/chunk selection strategies that achieve near-optimal performance trade-off.

### 6.2.3. Bandwidth conservation law

**Keywords:** *Peer-to-peer (P2P)*, *overlay network*, *peer-assisted*.

**Participants:** Farid Benbadis [France Telecom R&D, Issy Les Moulineaux, France], Nidhi Hegde [France Telecom R&D, Issy Les Moulineaux, France], Fabien Mathieu [France Telecom R&D, Issy Les Moulineaux, France], Diego Perino.

In any peer-to-peer or peer-assisted system, the sum of resources offered by peers at any time, is equal to the sum of resources they consume. In particular, the sum of data uploaded is equal to the sum of data downloaded: this is the bandwidth conservation law. In [4], we investigated performance bounds of most bandwidth-consuming applications including live streaming, VoD and file-sharing. By considering system features and requirements we studied several specific cases applied to the aforementioned P2P applications. Specifically, under the assumption of flat allocation (of upload rates), we describe the leverage effect that can be used to provide rates greater than the average peer upload capacity. We also provide a simple incentive model and show that the system can handle a given percentage of free-riders and can enter an over-provisioning state. We derive conditions on system parameters (such as the number of external servers, the required upload rates, the required Tit-for-Tat parameter, etc.) that can serve as guidelines for an ISP providing a peer-assisted service or for users tuning their application settings.

## 6.3. Multi-path routing

### 6.3.1. Modeling,Analysis and Design

**Keywords:** *Multi-path routing*, *congestion control*, *future networking*.

**Participants:** Luca Muscariello [France Telecom R&D, Issy Les Moulineaux, France], Bruno Nardelli [France Telecom R&D, Issy Les Moulineaux, France], Diego Perino, Dario Rossi [ENST, Paris, France].

Multi-path routing has been widely studied in literature. However, results are mainly theoretical and evaluation is normally performed over small network for few traffic demands. We derived an iterative optimization formulation of the multi-commodity flow problem (path-coordinated and path-uncoordinated traffic split) in order to analyze routing performance in typical CORE networks with hundreds of demands. Moreover, we designed a distributed algorithm aiming to achieve a network resource allocation similar to the one obtained by centralized optimization. We implemented this algorithm in a software prototype and performed some tests over real networks. Finally, we compared our algorithm to other solutions proposed in literature by means of fluid models. Results are currently under submission.

We investigated the impact of multi-path routing in metropolitan access networks. We considered current and future network architectures and traffic patterns to understand the conditions leading to significant benefit in applying multi-path routing. Results are currently under submission.

## 6.4. Tree-decomposition Application to the Internet

**Keywords:** *Tree-width*, *efficient computation*, *internet measurement*, *large graphs*, *tree-length*.

**Participants:** Fabien de Montgolfier, Mauricio Soto, Laurent Viennot.

The Internet graph (router and links) is quite large, dynamically evolving, and classical graph algorithm may thus not be used. Tree-decomposition approaches may then be tried for a better understanding of its structure, and for the design of efficent algorithms. Tree-decompositions include well-known tree-width (see for instance [12]), and the more recent tree-length. In this latter decomposition, the parameter to be optimized in the diameter of decomposition sets ("bags") instead of their size (as done with tree-width). Tree-length may be used for efficent computation of some network applications like compact distance labeling or compact routing tables [17]. We obtained results (not yet published) about bounds for tree-width and tree-length of the Internet graph. Tree-width is quite large, but tree-width small enough.

## 6.5. Distributed computing

**Keywords:** *distributed algorithm*, *minimum spanning tree*.

**Participants:** Pierre Fraigniaud, Amos Korman, Emmanuelle Lebhar.

### 6.5.1. Minimum spanning tree computation

In [21], we are interested in studying the efficiency of the crucial problem of the minimum spanning tree (MST) under the new framework of *advising schemes*. Specifically, while it is known that it takes at least $\sqrt{n}$ rounds to compute an MST in a distributed way without being given any bit of advice in the nodes, we show that, by providing only a constant number of bits of advice in each node, it is possible to compute an MST in a distributed way in just $O(\log n)$ rounds.

## 6.6. Efficient graph spanners

### 6.6.1. Distributed Computation of Sparse Spanner

**Keywords:** *ad hoc*, *bi-connectivity*, *k-connectivity*, *spanner*.

**Participants:** Bilel Derbel [CNRS LIFL, University of Lille, France], Cyril Gavoille [CNRS LABRI, University of Bordeaux, France], David Peleg [Weizmann Institute of Science, Israel], Laurent Viennot.

In [7] we provide distributed algorithms for computing sparse spanners. A spanner is a subgraph that preserves distances up to some stretch factor. Spanner computation is a first step towards compact routing, i.e. the achievment of a routing scheme where routers store few information compared to the size of the network.

## 6.7. Understanding graph decompositions

**Keywords:** *NLC decomposition*, *efficient graph algorithms*, *graph decompositions*, *modular decomposition*.

**Participants:** Binh-Minh Bui-Xuan [University of Bergen, Norway], Michel Habib, Vincent Limouzy, Fabien de Montgolfier, Michael Rao [CNRS LABRI, University of Bordeaux, France].

### 6.7.1. NLC decomposition

Many *width* graph decompositions have been proposed. Thanks to Courcelle theorem, they allow to efficiently solve many hard (NP-complete) problems for graph classes, provided the decomposition width is bounded. NLC decomposition is a variation of cliquewidth, where the decomposition is a labelled tree. In [28], the recognition of graphs of NLC 2 is addressed. The previous time complexity is improved to $(n^2m)$, and the algorithm is robust.

### *6.7.2. Umodular decomposition*

A new decomposition of combinatorial structures is presented in [13]. Is is based on a generalisation of the modular decomposition. When applied to undirected graph, it gives the bijoin decomposition, and when applied to tournaments, it gives a new decomposition. We present proofs of existence and uniqueness of a decomposition tree, and polynomial-time algorithms.

## 6.8. Discrete Optimization Algorithms

### *6.8.1. Three way decomposition of* $0-1$ *problems*

**Keywords:** *0-1 programming*, *global optimization*.

**Participants:** Dominique Fortin, Ider Tseveendorj [CNRS PRISM, University of Versailles Saint Quentin en Yvelines, France].

For $0-1$ optimization problems

$$\begin{cases} \min & f(x) \\ \text{s.t.} & x \in D \\ & x \in \{0,1\}^n, \end{cases} \qquad \text{(P)}$$

where $f(\cdot)$ is a convex function and $D$ is a convex body in $\mathbf{R}^n$, the difficulty lies in binary constraint $x \in \{0,1\}^n$, a nonconvex and discrete domain. We can write it in three different ways for an equivalent but continuous formulation:

$$x_i \in \{0,1\} \Leftrightarrow \quad \begin{array}{rl} i) & x_i(x_i-1)=0, \\ ii) & x_i(x_i-1) \le 0, x_i \le 0 \text{ or } x_i \ge 1, \\ iii) & x_i(x_i-1) \ge 0, 0 \le x_i \le 1, \end{array}$$

While the first is celebrated under the lift-and-project approach, we focused on the second, in the recent past, from the piecewise convex maximization optimization point of view; as for the third, it suggests to split the interval $[0,1]$ in $[0,\epsilon], [\epsilon, 1-\epsilon], [1-\epsilon, 1]$ and to record how many times a variable has been assigned to 0, middle value or 1 value in the continuous relaxation. It gives rise to an adaptative branch-and-bound strategy, independent of the problem itself, that interestingly competes with dedicated heuristics [1].

For global optimization problems, we improve our generic piecewise convex maximization algorithm by adding on demand, a new piece that allows to escape from a local optimum and give first result on simplest case when the problem reduces to $\max f(x), x \in D$ for $f, D$ both convex [2] in the particular case of multiknapsack.

# 7. Contracts and Grants with Industry

## 7.1. Collaboration with France Telecom (CRC Mardi)

**Participants:** Diego Perino, Dmitry Lebedev [France Telecom R&D, Issy Les Moulineaux, France], Fabien Mathieu [France Telecom R&D, Issy Les Moulineaux, France], Fabien de Montgolfier, Julien Reynier, Laurent Viennot, Simon Gwendal [France Telecom R&D, Issy Les Moulineaux, France].

MARDI is a collaboration contract between Inria and France Telecom. It gathers Gang and Spontex (FT) around the study of decentralized networks over Internet. Spontex is a transversal project on cooperative networks. Diego Perino is funded through this collaboration and co-supervised by Fabien Mathieu and Laurent Viennot.

### *7.1.1. Measuring Internet with and for peer-to-peer networks*

A first aspect of the project consist in studying Internet latencies in order to understand how logical overlays can be optimized with respect to delays. A possible track for gathering valuable large scale measures is to use a peer-to-peer network for measuring latencies. Interestingly, it is possible to find shortcuts in the Internet where the route through a relay can be faster than the direct route.

### *7.1.2. Modeling node and connection dynamics*

This item is connected to the affinity model where peers tend to connect preferentially to some peers based on some measured or inferred criteria. Connecting peers according to delays is a special case of affinity where a peer connects preferentially to peers with low RTT. Additional properties can be proven for this case to prove the convergence of a dynamic system following this low RTT strategy.

### *7.1.3. Peer-to-peer application design*

The third part of the project aims at designing efficient structuring algorithm for decentralized applications. It relies on the previous parts. Measuring and modeling Internet latencies can be used to obtain a first coarse solution to a fast overlay, and the affinity models can be use to tune the solution and to adapt it under node churn.

# 8. Other Grants and Activities

## 8.1. National initiatives

### *8.1.1. ANR grant Graph Decomposition and Algorithms (GRAAL)*

**Participants:** Binh-Minh Bui-Xuan [University of Bergen, Norway], Bruno Courcelle [CNRS LABRI, University of Bordeaux, France], Chritophe Paul [CNRS LABRI, University of Bordeaux, France], Cyril Gavoille [CNRS LABRI, University of Bordeaux, France], Fabien de Montgolfier, Michel Habib, Pierre Charbit, Stephan Thomasse [CNRS LIRMM, University of Montpellier II, France], Vincent Limouzy.

GRAAL is an ANR project “blanc” (i.e. fundamental research) about graph decompositions with LABRI and LIRMM. This project deals with fundamental aspects of computer science, namely theoretical and algorithmic aspects of decomposition methods for graphs and various combinatorial structures and extensions such as matroids, countable graphs... It proposes to combine approaches issued from graphs, discrete algorithms, formal languages and logic theory. We believe that major contributions to decomposition methods are no longer possible if each of these theories is considered separately.

### *8.1.2. ANR Algorithm Design and Analysis for Implicitly and Incompletely Defined Interaction Networks (ALADIN)*

**Participants:** Cyril Gavoille [CNRS LABRI, University of Bordeaux, France], Dominique Fortin, Emmanuelle Lebhar, Laurent Viennot, Michel Habib, Pierre Charbit, Pierre Fraigniaud, Vincent Limouzy.

Pierre Fraigniaud is leading an ANR project “blanc” (i.e. fundamental research) about the fundamental aspects of large interaction networks enabling massive distributed storage, efficient decentralized information retrieval, quick inter-user exchanges, and/or rapid information dissemination. The project is mostly oriented towards the design and analysis of algorithms for these (logical) networks, by taking into account proper ties inherent to the underlying infrastructures upon which they are built. The infrastructures and/or overlays considered in this project are selected from different contexts, including communication networks (from Internet to sensor networks), and societal networks (from the Web to P2P networks).

## 8.2. Actions Funded by the EC

### *8.2.1. COST 295 – Dynamo (2005-2009)*

Dynamo is an action of the European COST program (European Cooperation in the Field of Scientific and Technical Research) inside of the Telecommunications, Information Science and Technology domain (TIST). It is leaded by Pierre Fraigniaud (Chair of the managing committee). It gather more than 30 sites all over Europe around Dynamic Communication Networks. The Action is motivated by the need to supply a convincing theoretical framework for the analysis and control of all modern large networks. This will be induced by the interactions between decentralised and evolving computing entities, characterised by their inherently dynamic nature.

# 9. Dissemination

## 9.1. Services to the scientific community

- Laurent Viennot is a scientific editor of the )i(nterstices (http://interstices.info/) vulgarization site initiated by Inria in collaboration with french universities and Cnrs.
- Michel Habib is member of the steering committee of STACS (Symposium on Theoretical Aspects of Computer Science) and also of WG (International Workshop on Graph-Theoretic Concepts in Computer Science).

## 9.2. Teaching

Master MPRI Michel Habib is in charge of a course entitled “graph algorithms”. Laurent Viennot teaches ad hoc and web graph algorithms in the “networks dynamics” course;

D.U.T., University of Paris Diderot Yacine Boufkhad is teaching scientific computer science and networks (192 hours);

Computer Science U.F.R., University of Paris Diderot Fabien de Montgolfier is teaching foundation of computer science, algorithmics, and computer architecture (192 hours);

Master 2 Computer Science, University of Marne-la-Vallée Fabien de Montgolfier is teaching P2P theory and application;

Professional Master, Paris Diderot University Michel Habib is in charge of two courses untitled: Search Engines; Parallelism and mobility, which includes peer-to-peer overlay networks.

## 9.3. Theses

### *9.3.1. Ongoing theses*

- Vincent Limouzy *Algorithmes de décomposition de graphes* (MENRT) [defense 3 december 2008].
- Diego Perino *Mesures dans Internet par et pour les réseaux decentralisés* (CIFRE FranceTelecom).
- Mauricio Soto *Algorithmes de pair à pair et analyse de la structure d'Internet* (Chile-France Allocation).
- Anh Hoang Phan *Overlays structurés en pair à pair* (BDI).
- Hien Hu To *Décomposition de graphes* (AMX).

# 10. Bibliography

## Year Publications

### Articles in International Peer-Reviewed Journal

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