INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team mascotte

Méthodes Algorithmiques, Simulation et Combinatoire pour l'OpTimisation des TElécommunications

Sophia Antipolis

THEME COM

Activity Report

2004

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1. Team

MASCOTTE is a joint team between INRIA Sophia-Antipolis and the laboratory I3S (Informatique Signaux et Systèmes Sophia-Antipolis) which itself belongs to CNRS (Centre National de la Recherche Scientifique) and UNSA (University of Nice-Sophia Antipolis).

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Invited Researchers

Victor Almeida-Campos [University of Fortaleza (Brazil), 03/03/04 - 01/04/04]
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Aubin Jarry [Allocataire Moniteur Couplé, 3rd year]
Jean-François Lalande [Allocataire MENRT and ATER since 01/10/04]
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Yves Baumes [Projet ESSI (4.5 months)]
Louigi Addario-Berry [Doc McGill University (2 weeks)]
Laurent Braud [Magistère ENS Lyon (1.5 months)]
Arnaud Daver [Stage DEA RSD (5 months)]
Laurent Jouhet [Masgitère ENS Lyon (1.5 months)]
Marc Martinez de Albeniz [Pre-Doc UPC-Barcelona (6 months)]
Claudine Mossé [IUP GMI Avignon (4 months)]
Benjamin Nosenzo [Projet ESSI (4.5 months)]
Quang-Cuong Pham [Magistère ENS Paris (2.5 months)]
Ross Kang [Doc Oxford University (2 weeks)]
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Fabiano Sarracco [Doc. University of Roma (2 months)]
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2. Overall Objectives

MASCOTTE is a joint team between INRIA Sophia-Antipolis and the laboratory I3S (Informatique Signaux et Systèmes Sophia-Antipolis) which itself belongs to CNRS (Centre National de la Recherche Scientifique) and UNSA (University of Nice-Sophia Antipolis). Furthermore MASCOTTE is strongly associated with the center of research and development of France Télécom at Sophia-Antipolis via the CRC CORSO.

Its research fields are Simulation, Algorithmic, Discrete Mathematics and Combinatorial Optimization with applications to telecommunication or transportation networks.

In particular, MASCOTTE has developed in the last four years both theoretical and applied tools for the design of heterogeneous networks of various types (like WDM, SDH, ATM, wireless, satellites, ...).

On the one hand, the project aims to construct or design networks or communication algorithms. On the other hand, it also wants to build software simulators or to implement algorithms, but not to conceive protocols. The theoretical results can be applied to various situations and technologies.

3. Scientific Foundations

Keywords: *ATM networks*, *Algorithmic*, *Discrete Mathematics*, *SDP programming*, *Simulation*, *WDM or optical networks*, *approximation algorithms*, *combinatorial optimization*, *connectivity*, *discrete event systems*, *evolving or dynamic networks*, *fault tolerance*, *frequency allocation*, *graph theory*, *integer programming*, *network design*, *network flows*, *parallel and distributed computing*, *protection*, *road traffic simulator*, *satellite constellations*, *traffic grooming*, *virtual path layout*, *wireless networks*.

The project uses tools and theory in the following domains: Discrete Mathematics, Algorithmic, Combinatorial Optimization and Simulation. Typically, a telecommunication network (or an interconnection network) is modeled by a graph. A vertex may represent either a processor, a router, a switch or a person, and an edge (or arc) a connection between the elements represented by the vertices. We can add more information both on the vertices (for example what kind of switch is used, optical or not, number of ports, equipment cost) and on the edges (weights which might correspond to length, costs, bandwidth, capacities) or colors on paths etc. According to the application, various models can be defined and they have to be specified. This modeling part is an important task. To solve the problems, in some cases we can find polynomial algorithms: for example a maximum set of disjoint paths between two given vertices is by Menger's theorem equal to the minimum cardinality of a cut and it can be determined in polynomial time using graph theoretic tools or flow theory or linear programming. On the contrary, determining whether in a directed graph there exists a pair of disjoint paths, one from s_1 to t_1 and the other from s_2 to t_2, is an NP-complete problem, and so are all the problems which aim to construct or minimize the cost of a network which can realize certain traffic requests. On many problems, the project works with a deterministic hypothesis (for example if a connection fails it is considered as definitely and not intermittently). The project aims to construct or design networks or communication algorithms or to build software simulators or to implement algorithms but not to conceive protocols. The theoretical results can be applied to various situations and technologies.

4. Application Domains

For the last five years the project has chosen as main domain of application Telecommunication leaving the domain of parallel computing. The project has also applications in the domain of "transportation". However, note that there is some overlap between the two domains; in particular theoretical tools and also communication problems are not really different if one considers transportation or telecommunication networks. Inside the telecommunication domain the applications we consider are strongly dependent on the interest of the industrial partners with whom we collaborate. With France Télécom (and other partners) we have worked on the design of telecommunication backbone networks (either SDH/SONET, WDM, or ATM networks) and on various fault-tolerance (protection) problems (in particular in case of link failures) or grooming (grouping) of small traffic containers into bigger ones. We have also used the PROSIT simulation framework developed in the project both for applications to a road traffic simulator (in the OSSA E.U. project) or in the ASIMUT simulation environment for satellite telecommunication in particular with the CNES.

5. Software

5.1. Advanced Software

- PROSIT[1] is a sequential and distributed application framework for discrete event simulation. PROSIT uses object oriented techniques to allow for efficient development of complex discrete event simulation packages. It has been used as the simulation engine for the European projects HIPERTRANS and OSSA, devoted to high performance simulation of road traffic. It has also been at the heart of the ASIMUT simulation environment developed by CNES (the French National Space Centre) for satellite telecommunication systems evaluation.
  Licenses of PROSIT have been sold to CNES and to Dassault Data Systems.

5.2. Prototype Software

- MASCOPT[2]: the main objective of the MASCOPT (Mascotte Optimization) project is to provide a set of tools for network optimization problems [45][12]. Examples of problems are routing, grooming, survivability, and virtual network design. MASCOPT will help implementing a solution to such problems by providing a data model of the network and the demands, libraries to handle data and

[1] http://www-sop.inria.fr/mascotte/prosit/
[2] http://www-sop.inria.fr/mascotte/mascopt/

ready to use implementation of existing algorithms or linear programs (e.g. integral multicommodity flow).
MASCOPT is Open Source and intends to use the most standard technologies such as Java and XML format providing portability facilities. We finished to implement graph data structure, several basic algorithms working on graph and input/output classes. MASCOPT also provides some graphical tools to display graph results. We are currently writing network packages and performing experiments on WDM networks [55]. A first application has been released which computes on-board networks with fault tolerance which is described in section 6.3.

6. New Results

6.1. Discrete event systems and simulation

6.1.1. Simulation of Generalized DEVS models

Discrete Event Simulation (DEVS) is a modeling formalism that was initially proposed by Conception and Zeigler in 1988 to specify discrete event systems. This formalism allows a hierarchical modeling of systems: on the one hand it allows the definition of atomic models for each system component and on the other hand, it provides a coupling formalism to associate atomic components and build higher level components that may then be used themselves as atomic components. N. Giambiasi of LSIS (Marseille) introduced a Generalization of this formalism, called G-DEVS (1999) that extends the modeling capabilities of the DEVS formalism. Mascotte initiated a cooperation with LSIS, the MOEDIG project (supported by an INRIA COLOR funding) in order to study the G-DEVS formalism benefits through an implementation in the PROSIT simulation framework [47].

6.1.2. Road traffic Simulator

Preliminary work has been done by P. Mussi and A. Schwing [58] on methodologies to estimate road traffic by using instrumented vehicles, in complement of or instead of road sensors. This work will be carried out in 2005 in the framework of the MobiVIP project.

6.2. Network design

Designing a backbone network consists in computing paths for each traffic unit and then in assigning resources along these paths. The set of paths is chosen according to the technology, the protocol or the quality of service constraints. For instance, optical backbones use the WDM technology to take better advantage of the capacity of the optical fibers often already installed. This is achieved through multiplexing several wavelength channels onto the same fiber. In WDM networks, the huge bandwidth available on an optical fiber is divided into multiple channels. Each channel carries bandwidth up to several gigabits per second. A minimum unit of resource allocation is an optical channel, which consists of a path and a wavelength assigned on each link along the path and is called a *lightpath*. If wavelength translation is performed in optical switching, then each channel may be assigned different wavelengths on each link along the path; otherwise the wavelength continuity constraint must be satisfied on all links along the path. Of course, two lightpaths sharing a link must use different wavelengths on that link.

In MASCOTTE we have studied the wavelength routing and coloring problem, the traffic grooming problem and the virtual network embedding problem (with application to ATM networks) and other design problems for backbone telecommunication networks with SDH (Synchronous Digital Hierarchy) technology..

6.2.1. Traffic Grooming

Efficient optical routing aims to minimize the number of different wavelengths used in the network but also the number of electronic/optical conversions (hops for lightpaths). Another way for reducing the cost of the network is to group the traffic in such a way that some units of traffic may share some optical channels.

We address the problem of traffic grooming in WDM rings or paths with *All-to-All* uniform unitary traffic. The goal is to minimize the total number of SONET add-drop multiplexers (ADMs) required. We have shown that this problem corresponds to a partition of the edges of the complete graph into subgraphs, where each subgraph has at most C edges (where C is the grooming ratio) and where the total number of vertices has to be minimized. In preceding work, using tools of graph and design theory, we optimally solve the problem for rings for practical values and infinite congruence classes of values for a given C. In [48] we solve the problem for rings and $C = 6$. In [49] we study the problem for paths.

6.2.2. Reconfiguration of WDM networks

In a WDM network we assign to a new request the best possible route (if it exists) without computing a new routing for all requests. Thus, after several modifications of the set of requests, that is after a sequence of arrivals and terminations of requests, the routing may become inefficient. Furthermore, the probability of rejecting new requests may increase, even if there exists a routing for this set of request. So it is interesting to change the routing from time to time to improve the use of the resources in the network.

Given a set of requests and 2 different routings R_1 and R_2 for it, we want to find a set of modifications of the routing to go from R_1 to R_2, according to the following rules: (i) a request can use its new route if it is available (ii) we can move the route of a request to a temporary position at any time (iii) when a request uses a temporary route, it uses it until it can reach its final route. Our objective is thus to minimize the number of requests that are simultaneously in a temporary position.

We have modeled the problem in [51] and studied it on particular classes of graphs. In [56] we have proved that the problem is in general NP-complete and give an approximation for planar graphs.

6.2.3. Concave and Blossom constrained network design

In [42] we address a problem of network design with minimum cost, and uniform all-to-all demands between the vertices. We deal with the case of concave increasing link cost function f depending of the capacity over directed arcs. We obtain lower bounds for this problem. In the generic case $f : x \mapsto x^{\alpha}$, where $\alpha \in [0; 1]$, we exhibit some families that constitute a 1.12 asymptotic approximation of the optimal network. This technique suggests the preferable topologies that one may use when scale factors are varying.

The problem that we address in [54] is the classical problem of backbone network design for which we present two new classes of inequalities, one of valid inequalities and one of non-valid inequalities. These inequalities arise from the "blossom" constraints of the b-matching problem. We show that the separating problem over these classes of inequalities can be solved in polynomial time with respect to the dimension of the space in which the problem is defined. We point out the cases in which the valid inequalities are defining faces of the convex hull of the solution of the network design problem which we are dealing with. We give their Chvátal rank.

6.3. Fault tolerance

6.3.1. Connectivity and reliability.

In [15], we investigate the problem of finding a 2-connected spanning subgraph of minimal cost in a complete and weighted graph. We prove the first explicit lower bound on the approximability of this problem. On the other hand, we design an effective approximation algorithm if the input graphs satisfy the sharpened β-triangle inequality. Furthermore, we present an efficient approximation algorithm for the augmentation version of the problem in which a minimum-cost set of edges to a given graph G satisfying given edge- or vertex-connectivity requirements.

6.3.2. Fault tolerance in wireless networks.

In [26], we study hardness results and approximation algorithms of k-tuple domination in graphs. The k-tuple domination problem is a generalization of the dominating set problem in graphs in which each vertex of the graph has to be dominated at least k times. A main application to network purposes of k-tuple domination is for *fault tolerance* or *mobility* in the following situations. Each vertex of the graph models a node of the network and edges are links. Node u can use a service (any read-only data base for example) only if it is replicated on u or on a neighbor of u. To ensure a certain degree of fault tolerance or to tolerate mobility of nodes, one can imagine that any node u has in its (closed) neighborhood at least k copies of this service available. As each copy can cost a lot, the number of duplicated copies has to be minimized. This is the problem we study. In [26], we describe tight approximability and non-approximability results for general graphs, graphs of constant degree and p-claw free graphs.

6.3.3. *Minimum spanning subgraph*

When one wants to establish a multicast communication in a network, one searches for a low-cost substructure to be dedicated to this communication. Such a substructure must guarantee that a message can be sent from every member of the multicast group to any other. If we model the network by an undirected graph, this correspond to the Steiner Tree Problem which is known to be NP-Hard. However, if the multicast group consists of all the nodes of the networks, this is the minimum spanning tree problem which is easy. However, lots of networks may not be modelled by undirected graphs. For example, in an ad-hoc network a node a may be powerful enough to send some message to a node b while b is not powerful enough to do the converse. In [27], networks are modelled by directed graphs and the multicast group is the set of nodes of the networks. Hence we investigate the minimum spanning strong subdigraph problem. This problem is known to be NP-hard and the best known approximation algorithm of Vetta has ratio 1.5. We give an approximation algorithm with ratio $1 + 2\alpha/n$ where α is the stability number of the directed graph and n is its number of vertices. Hence our algorithm is better than the one by Vetta when $\alpha \leq n/4$, that is when the digraph is dense.

6.3.4. *Satellite boarded fault tolerant networks.*

Inside a telecommunication satellite, audio and video signals are routed through a switching network to amplifiers. Since it is impossible to repair a satellite, we choose to multiply the components that may be faulty, that is amplifiers and switches.

The first problem is to build a valid network which allows to route n input signals, to n amplifiers (outputs), arbitrarily chosen among $n + k$, and thus supporting k broken amplifiers. Each switch has 4 links and the routes followed by the signals must be disjoint. Thus for economical constraints, the objective is to build valid networks having the minimum number of switches.

In [40], we studied a variation of this problem where p of the input signals called priorities must be routed to the p amplifiers providing the best quality of service.

In [59] we considered the case where the number of failures is of the same order of n, typically the case $k = n$.

6.3.5. *Coalitions and Distributed Computing.*

In [13], we consider the question of the influence of a coalition of vertices, seeking to gain control in local neighborhoods in a general graph. This problem is motivated by fault tolerance and recovery applications in distributed computing, where decisions are taken after a voting process using a majority rule. Say that a vertex v is *controlled* by the coalition M if the majority of its neighbors are from M. We ask how many vertices (as a function of $|M|$) M can control in this fashion. Upper and lower bounds are provided for this problem, as well as for cases where the majority is computed over larger neighborhoods (either neighborhoods of some fixed radius $r \geq 1$, or all neighborhoods of radii up to r). In particular, we also look at the case where the coalition must control all vertices (including or excluding its own), and derive bounds for its size.

6.4. Resource sharing in wireless and sensor networks

6.4.1. *Radio networks : Internet in villages.*

Within the CRC CORSO with France Telecom, we have studied the problem of designing efficient strategies to provide Internet access using wireless devices. Typically, in one village several houses wish to access a gateway (a satellite antenna) and to use multi-hop wireless relay routing to do so.

On the one hand we have modeled the problem as follows. Each node (representing a house) is able to communicate to nodes not too far away (at distance at most d). On the other hand, there is interference between nodes (at distance at most d'). The distances can be measured either in terms of euclidean distances or number of hops. In our first study we have considered the special case where each node has one information (message) he wants to transmit to (or analogously receive from) the gateway (gathering problem). We have in particular obtained the results for specific topologies like paths or grids. In [53], we have considered the case where there is permanent demand (systolic algorithms). That leads to the definition of a *call scheduling problem*. In such networks the physical space is a common resource that nodes have to share, since concurrent transmissions cannot be interfering. We study how one can satisfy steady bandwidth demands according to this constraint. We show that it can be relaxed into a simpler problem: The *call weighting* problem, which is almost a usual multi-commodity flow problem, but the capacity constraints are replaced by the much more complex notion of non interference. Not surprisingly, this notion involves independent sets, and we prove that the complexity of the call weighting problem is strongly related to the one of the independent set problem and its variants (max-weight, coloring, fractional coloring). The hardness of approximation follows when the interferences are described by an arbitrary graph. We refine our study by considering some particular cases for which efficient polynomial algorithms can be provided: the *Gathering* in which all the demand are directed toward the same sink, and specific interference relations: namely those induced by the dimension 1 and 2 Euclidean space, those cases are likely to be the practical ones.

On the other hand, we have worked on the improvement of the norm 802.11b. In the case when all the stations see each other, we have studied a memory-based process where the stations automatically adapt to their environment to avoid too frequent emissions (which generates collisions) or too rare ones (which results in a loss of bandwidth). When the number of stations increases, the 801.11b norms makes the global capacity of the system tend to zero. In [33], we describe and study several alternatives, and we propose a solution where the total capacity of the system does not tend to zero but stays relatively high. Simulations show that this systems improves by 40% the capacity of the channel for 100 stations, and by 8% when the RTS/CTS mechanism is used. This study has opened the way to several developments in the CORSO contract.

In particular, in [57], we analyze the case where hidden stations are present through a Markov chain analysis. We obtain a precise analysis of the cases where communications can fail in the context of a chain of stations (i.e. each station sees at most two immediate neighbors).

In [52], we study distributed code allocation algorithms for *ad-hoc* CDMA networks. Several known and new algorithms are simulated and compared with respect to the knowledge of the neighborhood that each node has.

6.4.2. Resource allocation for a geostationary satellite

In some further work [39] we present an allocation algorithm for resources in satellite networks. It deals with the planning of the time/frequency plan for a set of terminals with a known geometric configuration and with interference constraints. The objective is to minimize the size of the frequency plan with the guarantee that the different types of demands are satisfied, each type using different bandwidth. The proposed algorithm uses two main techniques: the first generates admissible configurations for the interference constraints, the second uses mixed linear/integer programming with column generation. The obtained solution estimates a possible allocation plan with optimality guarantees and highlights the frequency interferences which degrade the construction of good solutions, improving drastically the simulated annealing approach previously proposed.

6.4.3. Energy efficiency.

In [36], we present a new heuristic called *Adaptive Broadcast Consumption* (ABC for short) for the *Minimum-Energy Broadcast Routing* (MEBR) problem. We first investigate the problem trying to understand which are the main properties not taken into account by the classic and well–studied MST and BIP heuristics, then we propose a new algorithm proving that it computes the MEBR with an approximation ratio less than or equal to MST, for which we prove an approximation ratio of at most 12.15 instead of the well–known 12. Finally, we present experimental results supporting our intuitive ideas, comparing ABC with other heuristics presented in the literature and showing its good performance on random instances even compared to the optimum.

In [31][46], we present new upper bounds on the approximation ratio of the Minimum Spanning Tree heuristic for the basic problem on *Ad-Hoc Networks* given by the *Minimum Energy Broadcast Routing* (MEBR) problem. In [31], we introduce a new analysis allowing to establish a 7.6-approximation ratio for the 2-dimensional case, thus significantly decreasing the previously known 12 upper bound (actually corrected to 12.15 in [36]). We also extend our analysis to any number of dimensions $d \geq 2$, obtaining a general approximation ratio of $3^d - 1$. The improvements of the approximation ratios are specifically significant in comparison with the lower bounds given by the kissing numbers, as these grow at least exponentially with respect to d. In [46], we introduce a new analysis allowing to establish a 6.33-approximation ratio in the 2-dimensional case, thus decreasing the 7.6 upper bound from [31].

6.4.4. Sensor networks

Wireless sensor networks have recently posed many new system building challenges. One of the main problems is energy conservation since most of the sensors are devices with limited battery life and it is infeasible to replenish energy via replacing batteries. An effective approach for energy conservation is scheduling sleep intervals for some sensors, while the remaining sensors stay active providing continuous service. In [32] we consider the problem of selecting a set of active sensors of minimum cardinality so that sensing coverage and network connectivity are maintained. We show that the greedy algorithm that provides complete coverage has an approximation factor of $\Omega(\log n)$, where n is the number of sensor nodes. Then we present algorithms that provide approximate coverage while the number of nodes selected is a constant factor far from the optimal solution.

The X*-rank* of a sensor s is the number of sensors whose X-coordinate is less than the X-coordinate of s. In [38] we provide a theoretical foundation for sensor ranking, in the case where some sensors know their locations and other sensors determine their *ranking* only by exchanging information. We show that in one dimension we can solve the ranking problem in linear time. On the other hand, the ranking problem is NP-hard in $\mathbb{R}^2$.

Some of the first routing algorithms for position-aware wireless networks used the Delaunay triangulation of the point-locations of the network nodes as the underlying connectivity graph. Later on these solutions were considered impractical because the Delaunay triangulation may in general contain arbitrarily long edges and because calculating the Delaunay triangulation may require a global view of the network. Many other algorithms were then suggested for geometric routing, often assuming random placement of network nodes for analysis or simulation. But as we show in [37], when the nodes are uniformly placed in the unit disk the Delaunay triangulation does not contain long edges, it is easy to compute locally and it is in many ways optimal for geometric routing and flooding.

Motivated by the study of sensor networks we consider the following problem in [44]:

Throw n points independently and randomly onto the n vertices of G. Remap the points on G such that the load of each vertex is exactly 1, minimizing the maximal distance that any point has to move (on G).

We call it the *Points and Vertices* problem. It may be viewed as an extension of the classical *Balls into Bins* problem, where m balls are thrown (independently and uniformly at random) into n bins, by adding graph-structural properties to the bins so that the bins become vertices and there is an edge between two vertices if they are “close” enough.

The interest in the Points and Vertices problem arises from the fact that it captures in a natural way the “distance” between the *randomness* of throwing points (independently and uniformly at random) onto the vertices of G, and the *order* of the points being evenly balanced on G. The problem also has important applications in several fields such as token distribution, geometric matching, wireless communications and robotics.

6.4.5. Frequency assignment.

Satellites send information to receivers on earth, each of which is listening on a frequency. Technically it is impossible to focus the signal sent by the satellite exactly on receiver. So part of the signal is spread in an area around it creating noise for the other receivers displayed in this area and listening on the same frequency. A receiver is able to distinguish the signal directed to it from the extraneous noises it picks up if the sum of the noises does not become too big, i.e. does not exceed a certain threshold T. The problem is to assign frequencies to the receivers in such a way that each receiver gets its dedicated signal properly. We investigate this problem in the fundamental case where the noise area at a receiver does not depend on the frequency and where the "noise relation" is symmetric that is if a receiver u is in the noise area of a receiver v then v is in the noise area of u. Moreover the intensity I of the noise created by a signal is independent of the frequency and the receiver. Hence to distinguish its signal from noises, a receiver must be in the noise area of at most $k = \lfloor \frac{T}{I} \rfloor$ receivers listening to signals on the same frequency.
Moreover, due to some practical reasons (as, for instance, the specific environment of a receiver), the frequency at each receiver must be chosen among a list of allowed ones for that receiver.

In [43], we model this problem in an improper list-colouring problem on some "noise graph". We give some results for graphs with bounded density which generalizes planar graphs and also contains noise graphs of practical instances.

6.5. Dynamic networks

6.5.1. Connectivity in evolving graphs.

New technologies and the deployment of mobile and nomadic services naturally engender new route-discovery problems under changing conditions over dynamic networks. Unfortunately, the temporal variations in the topology of dynamic networks are hard to be effectively captured in a classical graph model. We used evolving graphs, which helps capture the dynamic characteristics of such networks, in order to show that computing different types of strongly connected components in dynamic networks is NP-complete, and investigated the concepts of journeys in Evolving Graphs, which captures both space and time constraints in routing problems [19].

We further investigated the connected components problem in dynamic networks with special topologies. In a dynamic setting, the topology of a network derives from the set of all the possible links, past and future. We proved that the strongly connected components problem is still NP-complete when the topology is composed of unit disc graphs and the nodes are placed on a grid [35]. On the other hand, we also gave a polynomial-time algorithm, by dynamic programming, in order to compute a maximum strongly connected components when the topology is a tree [35].

One of the new challenges facing research in wireless networks is the design of algorithms and protocols that are energy aware. The *minimum-energy broadcast routing* problem, which attracted a great deal of attention these past years, is NP-hard, even for a planar static network. The best approximation ratio for it is a solution proved to be within a factor 12 of the optimal. One popular way of achieving this ratio is based on finding a Minimum Spanning Tree of the static planar network. We used the evolving graph combinatorial model to prove that computing a Minimum Spanning Tree of a planar network in the presence of *mobility* is NP-Complete [30]. We also gave a polynomial-time algorithm to build a rooted spanning tree of a mobile network, that minimizes the maximum energy used by any one node, thus maximizing the life-time of a wireless communication network [30].

6.5.2. Algorithms for the Web Graph.

In [29], we study the size of generalised dominating sets in two graph processes which are widely used to model aspects of the world-wide web. On the one hand, we show that graphs generated this way have fairly large dominating sets (i.e. linear in the size of the graph). On the other hand, we present efficient strategies to construct small dominating sets. The algorithmic results represent an application of a particular analysis technique which can be used to characterise the asymptotic behaviour of a number of dynamic processes related to the web.

6.5.3. Algorithms for the Internet.

In [25], we introduce the Push Tree problem which contains elements from both the Steiner Tree and the Shortest Path problem. The Push Tree problem deals with the trade-offs between the push and pull mechanisms used in information distribution and retrieval in the Internet. We present some initial complexity results and analyze several heuristics. Moreover, we discuss what lessons can be learnt from the static and deterministic Push Tree problem for more realistic scenarios characterized by high uncertainty and changing information request and update patterns.

6.5.4. Modelling of Peer-to-Peer networks.

In [50], we consider a randomized algorithm for assigning neighbours to vertices joining a dynamic distributed network. The algorithm acts to maintain connectivity, low diameter and constant vertex degree. This is effected as follows: On joining each vertex donates a fixed number of tokens to the network. The tokens contain the address of the donor vertex. Tokens make independent random walks in the network. A token can be used by any vertex it is visiting to establish a connection to the donor vertex. This allows joining vertices to be allocated a random set of neighbours although the overall membership of the network is unknown. The network we obtain in this way is robust under adversarial deletion of vertices and edges and actively reconnects itself.

6.6. Graph Theory and Communication

6.6.1. Information dissemination

With the rapid developments in hardware technologies, distributed computing and the interconnected world became realities, and the term "communication" became central in computer science. Solving communication tasks under different circumstances is the topic of this textbook [11]. It provides an introduction to the theory of design and the analysis of algorithms for the dissemination of information in interconnection networks, with a special emphasis on broadcast and gossip. The book starts with the classic telegraph and telephone communication modes and follows the technology up to optical switches. Despite the rigorous presentation, simplicity and transparency are the main learning features of this book. All ideas, concepts, algorithms, analyses and arguments are first explained in an informal way in order to develop the right intuition, and then they are carefully specified in detail. This makes the content accessible for beginners as well as specialists.

In [20], we determine lower bounds on the broadcasting and gossiping time required by the so-called restricted protocols. Informally, a protocol is $(\mathcal{I}, \mathcal{O})$-restricted if at every processor each outgoing activation of an arc depends on at most $\mathcal{I}$ previous incoming activations and any incoming activation influences at most $\mathcal{O}$ successive outgoing activations. Examples of restricted protocols are systolic ones a nd those running on bounded degree networks. Thus, under the basic whispering model, we provide the first general lower bound on the gossiping time of d-bounded degree networks in the directed and half-duplex cases. Moreover, significantly improved broadcasting and gossiping lower bounds are obtained for well-known networks such as butterfly, de Bruijn, and Kautz graphs.

6.6.2. Orientations and colourings of graphs.

Orientations and colourings of graphs are related in different ways but the deepness of these relations is not well understood. One of the results relating orientations to colouring is the Gallai-Roy Theorem. It states that the chromatic number of a graph is the minimum over all its orientations of the order (number of vertices) of a longest path. In 1982, Laborde, Payan and Xuong formulated the following conjecture implying the Gallai-Roy Theorem: Every oriented graph contains a stable set intersecting every longest paths. In [24], we prove this result for oriented graphs with stability at most 2.

Another way to extend the Gallai-Roy Theorem is in terms of unavoidable substructures of k-chromatic graphs. Indeed, this theorem easily implies that every k-chromatic oriented graph contains a directed path of length k. A natural problem is: what are the oriented graphs that are contained in every k-chromatic oriented graphs? Since k-chromatic graph may have girth (length of a smallest cycle) as large as we want, such unavoidable oriented graphs must be oriented trees (orientations of trees). Since the complete graph with k vertices is the easiest k-chromatic graph, a first step is to consider the unavoidability of oriented trees in tournaments (orientation of complete graphs). Havet and Thomassé conjectured in 2001 that every oriented tree of order n with k leaves is contained in every tournament of order $n + k$. In [18], we prove that this conjecture is true if $k = 3$ and a stronger result: every oriented tree (with one exception) of order n with 3 leaves is contained in every tournament of order $n + 1$.

6.6.3. Edge coloring.

In [16], we study the Bipartite Edge Coloring problem where some of the edges have been previously colored. We wish to complete the coloring of the edges while minimizing the total number of colors used. This problem is NP-hard even for bipartite graphs of maximum degree three and the best known approximation algorithm have a 3/2 ratio. Using techniques motivated by recent works on Circular Arc Coloring problem, we develop a randomized (1.37+o(1))-approximation algorithm. This algorithm works with high probability provided that the optimal number of colors is large (i.e. $\omega(\log n)$).

6.6.4. Structural properties of digraphs.

In [28], we present three new min-max theorems on digraphs. They all concern cyclic order of digraphs which is a new way for ordering the vertices of a strong digraph while getting some nice properties on its circuits. These theorems are powerful and allow us to prove the celebrated conjecture of Gallai (1963): every strong digraph with stability α is spanned by α circuits.

In [23], we investigate the number of pancyclic arcs in a tournament. We give a simple proof of the result of Moon that every strong tournament has at least 3 pancyclics arcs. We then show lower bounds on the number of pancyclics arcs on a tournament as a function of its connectivity. This allow us to completely describe the tournaments with exactly 3,4,5 and 6 pancyclic arcs.

6.6.5. Arc-colouring and function theory

Let f and g be two functions from a finite set E into a set F. If f and g never coincides (i.e. $f(x) \neq g(x)$ for all $x \in E$), we seek for the minimum number of (f, g)-independent sets to cover E, where a set $I \subset E$ is (f, g)-independent if $f(I) \cap g(I) = \varnothing$. This problem may be transformed into an arc-colouring problem of some graph. Hence, motivated by function theory, we study [41] the maximum value $\Phi^{\vee}(k, l)$ of the arc-chromatic number over the digraphs in which a vertex has either outdegree at most k or indegree at most l.

6.6.6. 2-commodity flows.

We studied integral 2-commodity flows in networks with a special characteristic, namely symmetry. Symmetric networks represent a generalization of optical telecommunication networks, in which optical links are composed by pairs of opposite unidirectional optical fibers. We showed that the Symmetric 2-Commodity Flow Problem is polynomial, by proving that the cut criterion is a necessary and sufficient condition for the existence of a solution. We also gave an efficient algorithm which requires only six simple flow computations [34]. This result closed an open question in a surprising way, since it is known that the Integral 2-Commodity Flow Problem is NP-complete in most graph families.

6.6.7. Search in a network

We study a problem related to the search in an anonymous and unknown network. In this model the nodes of the network have only a local and partial knowledge of the network and therefore the search algorithm needs to be independent of the topology. The cost of the algorithm can be measured either by the completion time (expressed in number of rounds) or by the number of messages sent.

In [22] we minimize the broadcasting time; we study two variants according to whether the time is the one to broadcast the information or the one needed for the sender to know that the broadcast has succeeded.

7. Contracts and Grants with Industry

7.1. Contract cre France Télécom R&D

Keywords: *Design of telecommunication networks*, *Matching*, *Protection*, *Routing*.

Contrat de recherche externalisé (*CRE*) with France Télécom R&D, 2003-2005, on matching constrains for the design of telecommunication networks. This contract covers mainly the PhD grant of S. Petat.

7.2. Contract crc France Télécom R&D

Keywords: *Design of telecommunication networks*, *Fault Tolerance*, *Radio Networks*.

Contrat de recherche collaborative (*CRC*) with France Télécom R&D, 2003-2005.

As mentioned earlier, we have a strong collaboration with France Télécom R&D inside the CRC CORSO. This means that some researchers of MASCOTTE on one side and engineers of France Télécom R&D on the other side work together on specified subjects approved by a "Comité de pilotage". Among these subjects we can cite the design of telecommunication networks, the study of fault tolerance and the use of radio networks for bringing Internet in places where there is no ADSL.

8. Other Grants and Activities

8.1. National Collaborations

8.1.1. Action MobiVip

MobiVIP is a PREDIT project funded by Ministries of Research, Transportation, Industry and Environment, together with ANVAR and ADEME. In this program, 5 research laboratories and 7 SMEs work in collaboration to experiment, demonstrate and evaluate a new transportation system for cities, based on intelligent small urban vehicles. Mascotte will develop methods for traffic estimation based on instrumentation of those vehicles.

http://www-sop.inria.fr/mobivip/

8.1.2. ATIP Jeunes Chercheurs

Atip jeunes chercheurs CNRS, August 2002 - July 2004, on frequency allocation problems in cellular networks.

8.1.3. Aci sécurité "Presto"

Aci sécurité: "PRESTO**"**, 2003- 2006, on survivability of communication networks, in collaboration with the ENST (Paris) and the LIMOS (Clermont-Ferrand).
(http://www-sop.inria.fr/mascotte/David.Coudert/PRESTO/)

8.2. European Collaborations

8.2.1. European project RTN Aracne

European project RTN: "ARACNE**"**, 2000-2004, on Approximation and Randomized Algorithms for Communication Networks, in collaboration with the universities of Salerno (coordinator) and Roma (Italy), Patras (Greece), Geneva (Switzerland) and Kiel (Germany). The goal of this project is to study communication problems and network designs from the algorithmic side.

8.2.2. European project IST CRESCCO

European project Ist : "CRESCCO**"**, 2002-2005, on critical resource sharing for cooperation in complex systems, in collaboration with the universities of Salerno and Roma (Italy), Patras (Greece, coordinator), Geneva (Switzerland) and Kiel (Germany). Mascotte works essentially on the efficient use of bandwidth in WDM networks (Workpackage 4).

(http://www.ceid.upatras.gr/faculty/kakl/crescco).

8.2.3. European COST 293

European COST Action: "COST 293, GRAAL", 2004-2008. The main objective of this COST action is to elaborate global and solid advances in the design of communication networks by letting experts and researchers with strong mathematical background meet peers specialized in communication networks, and share their mutual experience by forming a multidisciplinary scientific cooperation community. This action has more than 25 academic and 4 industrial partners from 18 European countries. Mascotte works essentially on the design and efficient use of optical backbone network.

(http://www.cost293.org).

8.2.4. European COST 355

P. Mussi has joined COST Action 355 **"Changing behaviour towards a more sustainable transport system"**. The main objective of this COST Action is to develop a more rigorous understanding of the conditions under which the process of growing unsustainable transport demand could be reversed, by changing travellers, shippers and carriers behaviour.

http://cost.cordis.lu/src/action_detail.cfm?action=355

8.2.5. Proposal of a Network of Excellence, Saga

Proposal of a Network of Excellence: "SAGA**"**, 2003, on structural and algorithmic aspects of communication networks, in collaboration with 51 European research centers and 28 European companies. Unfortunately, this proposal has not been accepted; but it has strengthened the collaboration between various groups in Europe and there was a successful workshop and the proposal will be resubmitted.

Funds are given by the ministry to pursue this collaboration in 2004.

8.2.6. Bilateral Cooperation Cnrs–Oxford

Cooperation CNRS**–Oxford**, 2003-2005, on frequency allocation problems in wireless networks, in collaboration with the Mathematical Institute of Oxford University.

Funded by the PACA province.

8.2.7. Royal Society Grant with King's College London

Bilateral Cooperation, 04/2004-03/2006, on "Web Graphs and Web Algorithms", in collaboration with the Department of Computer Science, King's College London.

Funded by the ROYAL SOCIETY, U.K.

8.3. International Collaborations

8.3.1. Cooperation Inria–Brazil Regal

Cooperation INRIA**–Brazil: "**REGAL**"**, 2003-2006, on algorithmic problems for telecommunication networks, in collaboration with the Federal University of Ceara (Fortaleza, Brazil).

Funded by the PACA province (06/04-06/06).

8.3.2. Join team with the Network Modeling Group (sfu, Vancouver, Canada) : "ReseauxCom"

One of the main objectives is to strengthen our collaboration with SFU. Many reciprocal visits have been performed.

(http://www-sop.inria.fr/mascotte/David.Coudert/EquipeAssociee/)

8.4. Visitors

- *Louigi Addario-Berry*, McGill University (Canada), 20/09/04 - 01/10/04.
- *Victor Almeida-Campos*, University of Fortaleza (Brazil), 03/03/04 - 01/04/04.

- *Colin Cooper*, King's College London (UK), 21/11/04 -26/11/04.
- *Ricardo Correa*, University of Fortaleza (Brazil), 02/11/04 - 29/11/04.
- *Alfredo Goldman*, University of Sao Paolo (Brésil), 01/10/04 - 09/10/04.
- *Pavol Hell*, Simon Fraser University (Canada), 07/11/04 - 20/11/04.
- *Ross Kang*, Oxford University (UK), 27/09/04 - 12/10/04.
- *Evripides Markou*, University of Athens (Greece), 15/11/04 - 24/11/04.
- *Joseph Peters*, Simon Fraser University (Canada), 12/05/04 - 19/07/04.
- *Tomasz Radzik*, King's College London (UK), 19/04/04 - 24/04/04 and 04/10/04 - 03/12/04.
- *Fabiano Sarracco*, University of Roma (Italy), 08/11/04 - 25/03/05.
- *Joseph Yu*, Simon Fraser University (Canada), 01/02/04 - 30/04/04 and 14/06/04 - 30/06/04.

8.5. Stays abroad

- *J.-C. Bermond*: Fortaleza (Brazil) 17/01/04-09/02/04, CTI Patras (Greece) 05-21/06/04, S.F.U. Vancouver (Canada) 24/08/04-1/10/04.
- *D. Coudert*: S.F.U. Vancouver (Canada) 16/08/04-17/09/04.
- *A. Ferreira*: Sao Paolo and Fortaleza (Brazil) 09/02/04-07/03/04.
- *R. Klasing*: S.F.U. Vancouver (Canada) 31/01/04-28/02/04, King's College London (UK) 25/07/04-01/08/04.
- *J-F. Lalande*: Kiel (Germany) 11-25/05/04.
- *A. Laugier*: Otto von Guericke University, Magdeburg (Germany) 11/04.
- *A. Navarra*: L'Aquila (Italy) and Athens (Greece) 03-29/05/04.
- *S. Pérennes*: L'Aquila (Italy) 01-30/11/04.
- *H. Rivano*: DISI, Genova (Italy) 01/03/04-01/06/04 (part time).
- *M. Syska*: Kiel (Germany) 11-25/05/04, S.F.U. Vancouver (Canada) 16/08/04-17/09/04.

9. Dissemination

9.1. Leadership within the scientific community

9.1.1. Participation in Committees

- *J-C. Bermond*: expert for RNRT; member of the scientific committee of LIRMM (Montpellier); member of the "Commission de Spécialistes de la 27^{e} section" of UNSA; substitute member of the "Commissions de Spécialistes de la 27^{e} section" of UTC (université de Technologie de Compiègne) and Université de la Méditerranée (Aix-Marseille II); member of the I3S Project Commitee; nominated member of the RTP (réseaux thématiques) Commitee of STIC department " Réseaux " and " Mathématiques de l'Informatique "; member of the PhD committee of Marseille and of the "Conseil Scientifique" of the Ecole Doctorale STIC of Nice-Sophia antipolis.
- *M. Cosnard* : chair of the ACI GRID ; substitute member of the Commission de Spécialistes 27^{e} section of ENS Lyon ; chair of the conseil scientifique of CINES.
- *D. Coudert*: secretary for the INRIA Sophia Antipolis Project Committee until April 04; secretary substitute afterward; member of the COST Action 293 Management Committee.
- *O. Dalle* : member of working group "Vers une théorie de la Simulation" (http://www.lsis.org/versim/), member of the “Commission de Spécialistes 27^{e} section” of UNSA, member of the “Commission du Développement Logiciel” de l'INRIA Sophia Antipolis, member of the “Comité Informatique” of I3S.
- *A. Ferreira*: nominated member of the I3S laboratory Commitee; member of the "Commission d'évaluation" of the INRIA; member of the RNRT commission 3; member of the CNRT Telius board.
- *J. Galtier*: member of the COST Action 293 Management Committee.
- *F. Havet*: member of the I3S laboratory Committee, of the "Commission de Spécialistes de la 25^{e} et 26^{e} section" of the University of Lyon 1, and of the "Commission de Spécialistes de la 27^{e} section" of the University of Montpellier II.
- *R. Klasing*: substitute member of the I3S laboratory Committee.
- *A. Laugier*: refeeree for ACI "Nouvelles interfaces des mathématiques".
- *P. Mussi*: head of the ReV department (public relations, international and industrial partnerships) of INRIA Sophia Antipolis, member of the "Commission de Spécialistes de la 27^{e} section" of University of Nice-Sophia Antipolis, member of working group "Modélisation Multiple et Simulation" (GdR MACS, http://mad3.univ-bpclermont.fr/), and working group "Vers une théorie de la Simulation" (http://www.lsis.org/versim/).
- *M. Syska*: nominated member of the I3S laboratory Committee as president of "Commission informatique".

9.1.2. Editorial Boards

- *J-C. Bermond*: Combinatorics Probability and Computing, Discrete Mathematics, Discrete Applied Mathematics, Journal of Graph Theory, Journal Of Interconnection Networks (Advisory Board), Mathématiques et Sciences Humaines, Networks, Parallel Processing Letters and the SIAM book series on Discrete Mathematics.
- *M. Cosnard*: Editor-in-Chief of Parallel Processing Letters. Member of the Editorial Board of Parallel Computing, of Theory of Computational Systems (TOCS) and of IEEE TPDS.
- *A. Ferreira*: Journal of Parallel and Distributed Computing (Academic Press), Parallel Processing Letters (World Scientific), Parallel Algorithms and Applications (Elsevier), Journal of Interconnection Networks (World Scientific).

9.1.3. Steering Committees

- *M. Cosnard*: SPAA - *Symposium on Parallel Algorithms and Architectures* (2001-2004), PACT (Chair) *Parallel Computing Technologies* (2002-2005) - IFIP Working Group 10.3.
- *A. Ferreira*: AlgoTel, Ecotel, DialM.

9.1.4. Workshop organization

D. Coudert, O. Dalle and E. Deriche organized the 6th Winter School on Telecommunications (EcoTel'04), 2-9/12/04, Zarzis, Tunisia.

9.1.5. Participation in program committees

- *A. Ferreira*: CLADE, WCSF, WWAN.
- *F. Havet*: co-chair of ALGOTEL 2004.
- *J. Galtier*: Networking 2004.
- *A. Laugier*: Graph Theory 2004.
- *P. Mussi*: CSM04, PDCN 2004, Majecstic'04.

9.2. Teaching

9.2.1. Theses

- The following theses have been passed in 2004: *J.-F. Lalande*: Conception de réseaux de télécommunications : optimisation et expérimentations, ESSI, December 10th;
- The following theses are in preparation:
  G. Huiban: La reconfiguration dans les réseaux optiques multifibres;
  A. Jarry: Connexité et protection dans les réseaux de télécommunications;
  N. Morales: Méthodes d'approximation pour les problèmes de réseaux de télécommunications avec de contraintes économiques et de traffic incertain;
  S. Petat: Contraintes de couplages pour la conception de réseaux de télécommunications;
  J-S. Sereni: Coloration par listes appliquée à l'allocation de fréquences;
  M-E. Voge: Protection et groupage dans les réseaux de télécommunications.

9.2.2. Member of Ph.D. Committees

- *J-C. Bermond and M. Syska*: members of the Ph.D. Committee of J-F. Lalande (University of Nice-Sophia Antipolis).
- *R. Klasing*: External Ph.D. reviewer of P. Chen (S.F.U., 06/08/04), member of the Ph.D. Committee of C. Destré (University of Evry, 06/12/04).
- *M. Cosnard*: member of many Ph.D. and HdR Committees.

9.2.3. Internships

- *R. Klasing* supervised the preDoc internship of Fabiano Saracco (University of Roma)
- *D. Coudert* supervised the internship of Laurent Braud (ENS Lyon)
- *D. Coudert* supervised the internship of Quang Cuong Pham (ENS Ulm)
- *D. Coudert* supervised the master of Arnaud Daver (DEA RSD)
- *H. Rivano* supervised the internship of Laurent Jouhet (ENS Lyon)
- *D. Coudert* supervised the master of Marc Martinez de Albeniz (UPC Barcelona)
- *D. Coudert and M. Syska* supervised the internship of Claudine Mossé (IUP Avignon)
- *J. Galtier* supervised the master of Ludovic Samper (DEA MDFI, Marseille)
- *J-C. Bermond and S. Pérennes* supervised the internship of Jeremy Serror (Magistère Paris VII)
- *P. Mussi* supervised the master of Alejandro Acosta (Master ENST Bretagne)
- *P. Mussi* supervised the master of Alexandre Schwing (Master Ecole Polytechnique Marseille)
- *M. Syska* is supervising the project of Yves Baumes and Benjamin Nosenzo (ESSI).

9.2.4. Teaching

The members of MASCOTTE strongly participate in a lot of teaching activities in undergraduate studies (DEUG, IUT, Licence Maîtrise, Engineering Schools like ESSI). The teaching is insured by members of the University as their teaching duties and for INRIA CNRS or PhD's as extra work. It represents more than 1000 hours per year.

For graduate studies, MASCOTTE was strongly involved in the creation of the DEA RSD (Réseaux and Systèmes Distribués) and now members of MASCOTTE teach both in the mandatory lectures and in 3 options of the DEA RSD. Members of MASCOTTE are also involved in teaching in other DEA's like the DEA MDFI of Marseille or in DESS like the DESS Telecoms or in the 3rd year of engineering schools. Altogether that represents around 200 hours per year.

The members of MASCOTTE supervise on the average around 20 internships per year at all levels (Maîtrise, Engineering School, DEA). The students come from various places in France as well as from abroad (e.g. Europe, Chile, United States, India). Some of the internship reports are listed in the bibliography under the heading miscellaneous.

9.3. Participation in conferences and workshops

9.3.1. Invited talks

- *J-S. Sereni*: LaPCS, Lyon, January 21st.
- *R. Klasing*: Network Modeling Group seminar, S.F.U., Vancouver, Canada, February.
- *M. Syska*: Research Group Discrete Optimization, Kiel, Germany, May 18th.
- *F. Havet*: LIRMM, Montpellier, July 1st.
- *A. Jarry*: Operations Research 2004, Tilburg, Netherland, September 1-3rd.
- *M. Syska*: NMG seminar, S.F.U., Vancouver, Canada, September 10th.
- *J-C. Bermond*: NMG seminar, S.F.U., Vancouver, Canada, September.
- *F. Havet*: LaBRI, Bordeaux, December 3rd.
- *S. Bessy*: Ecole Polytechnique de Lausanne, Switzerland, December 16th.

9.3.2. Participation in scientific meetings

- *P. Mussi* attended the MobiVIP kickoff meeting, Paris, January 15th.
- *A. Ferreira and R. Klasing* attended the CRESCCO and ARACNE 2 preparation meeting, Roma, Italy, January 19-20th.
- *J-F. Lalande* attended "Rencontres INRIA-Industrie", Rocquencourt, January 27th.
- *P. Mussi* attended the Versim working group meeting, Marseille, February 9th.
- *P. Mussi* attended the MMS working group meeting, Villeurbanne, February 13th.
- *M. Syska* attended the RTP "Réseaux de Communication", Carcassonne, April 8-9th.
- *P. Mussi and O. Dalle* attended the Versim working group meeting, Montpellier, May 11th.
- *J-S. Sereni* attended "Deuxième Journée de Combinatoire Rhônes-Alpes", Grenoble, May 19th.
- *D. Coudert, J. Galtier, J-F. Lalande, A. Laugier, S. Petat and M-E. Voge* attended the "Optimization Seminar of France Telecom R&D", Sophia Antipolis, June 2-4th.
- *D. Coudert and S. Perennes* attended the CRESCCO meeting, Athens, Greece, July 26-27th.
- *J-C. Bermond, D. Coudert, J-F. Lalande, H. Rivano, M-E. Voge* attended the meeting of the ACI PRESTO, Clermont-Ferrand, October 4th.
- *D. Coudert, A. Jarry, R. Klasing, J-F. Lalande, N. Morales, H. Rivano and M-E. Voge* attended the TAROT meeting, Lyon, October 14-15th.
- *D. Coudert* attended the COST Action 293 kick off meeting, Brussels, Belgium, October 20th.
- *D. Coudert and H. Rivano* attended the ACI-SI meeting, Toulouse, November 15-17th.
- *P. Mussi* attended Cost 355 meeting, Namur, December 1-2nd.

9.3.3. Participation in conferences

- *D. Coudert and M. Syska* attended Global Computing'04, Trento, Italy, March 8-10th.
- *A. Jarry* attended WiOpt'04, Cambridge, UK, March 24-26th.
- *A. Jarry* attended STACS'04, Montpellier, March 25-27th.
- *D. Coudert and F. Havet* attended AlgoTel'04, Batz-sur-Mer, May 26-28th.
- *A. Navarra* attended Networking 2004, Athens, Greece, May 9-14th.
- *G. Huiban* attended Optimization 2004, Lisbon, Portugal, May 25-28th.
- *J-F. Lalande* attended JNPC'04, Anger, June 21-23th.
- *M-E. Voge* attended the First Workshop on Algorithms for Scheduling and Communication, Bertinoro, Italy, 27/06/04-03/07/04.
- *F. Havet, J. Galtier, A. Laugier and J-S. Sereni* attended GT'2004, Paris, July 5-9th.
- *J. Galtier* attended ITC Specialist Seminar 2004, Antwerpen, Belgium, 31/08/04-02/09/04.
- *A. Jarry* attended DIALM-POMC 2004, Philadelphia, USA, October 1st.
- *J-C. Bermond and M. Syska* attended the CRESCCO meeting and workshop, Roma, Italy, October 16th.

9.3.4. Participation in schools

- *D. Coudert, E. Deriche, G. Huiban, J-F. Lalande, N. Morales, P. Mussi, H. Rivano, J-S. Sereni and M-E. Voge* attended the the 6th Winter School on Telecommunications (EcoTel'04), 2-9/12/04, Zarzis, Tunisia.

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