Acronyme	**DIMAGREEN**		
Titre du projet en français	Conception et gestion de réseaux verts à basse consommation d'énergie		
Titre du projet en anglais	**D**es**I**gn and **MA**nagement of **GREEN** networks with low power consumption		
CSD principale	☒ **1** ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9		
CSD secondaire ***(si interdisciplinarité)***	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9		
Aide totale demandée	188 931 €	**Durée du projet**	36 mois

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1. CONTEXTE ET POSITIONNEMENT DU PROJET / CONTEXT AND POSITIONNING OF THE PROPOSAL

The face of Internet has dramatically changed over the last few years, from a small community of specialists with research and engineering needs to a space with billions of users using it in their daily life. Jupiter research expects the number of users to attain up to 1.5 billions in 2008 from 1.1 in 2006, representing a growth of 36% in only 2 years. At the same time, new applications appear, like social networking (e.g. Facebook) to share, keep the contact with friends, family or people with common interests. This new usages make network traffic drastically grows, with an expected acceleration of this trend in the near future [7,8]. For example, a recent note on clubic.com evokes the multiplication by four of the peer to peer traffic in the five next years. This increasing number of users with new needs and ways of being connected to the Internet modifies the characteristics of the network and the dynamic of traffic in the following ways:

- **New traffic concentrated on huge data centers:** the development of search engines, large systems of video on demand (e.g. youtube), and of cloud computing, make that a large part of the traffic is concentrated on huge data centers. This phenomenon *changes the topology* of the Internet. This change depends on the applications deployed and used in the network with opposite effects between P2P and data center applications.

- **Mobility of users:** the usage of mobile devices like laptops and cellular phones spreads and operators are developing multimedia applications for the new smartphones. Their users more and more require to be able to use these applications without experiencing any disruption, e.g. video streaming in a train.

- **Strong variation of users traffic:** the video streaming of popular events and the development of social sharing create communities of users wanting to access a multimedia content. Hence, a large number of users may try to connect to the same resource at the same time. This leads to a highly dynamic traffic load and possible sharp peaks in traffic rates.

Therefore new solutions have to be invented for network design and management to take into accounts these new constraints and needs. These changes have to been done in a society facing specific new challenges.

A new context.

With the increased cost of energy and the sharp growth of demand, the need of energy-aware solutions has appeared as an imperative for governments, companies and individuals. This thematic is also particularly relevant for the networking community. For example, as of 2006, the electricity usage attributable to the servers and data centers in the US is estimated at about 61 billion kilowatt-hours (kWh), or also 1.5% of total U.S. electricity consumption.

Between 2000 and 2006, this usage more than doubled, amounting to about $4.5 billion in electricity costs. It's poised to double again by 2011. Hence a very important objective is the reduction of the energy consumption to operate and manage the existing networks, especially with the development of demanding new applications.

To reduce the power consumption induced by Internet, several techniques can be studied:

1. **At the hardware level:** the overall consumption of the network can be reduced by technological progresses in the creation of network equipments, e.g. more efficient cooling systems or the introduction of different hardware states depending on the level of activity.

2. **At the network design level:** the networks need to be conceived to suite the new needs and applications of users. For example, changes in topologies and well distributed replications of the data are a way to reduce the resources used by the networks.

3. **At the network management level:** when the network has been already designed, new routing policies taking the power consumption into account can be introduced.

During this project, we will focus mainly on the design and management of networks, as there plainly are in the scope of our competences.

Finally, the main objectives of this project will be to *introduce and analyze energy-aware networks.* This will lead to increasing the life-span of telecommunication hardware and to reducing the energy consumption together with the electricity bill.

In order to achieve the main goal of the project, we plan to propose:

- New cost functions for the network devices (e.g. routers) via measures and models of their consumption in function of their load and other hardware constraints.

- New tools for designing energy efficient networks, based on the analysis of the new changes of network topology.

- Efficient routing policies, that takes into account the new characteristics of Internet traffic, e.g. the strong variation of user traffic.

2. DESCRIPTION SCIENTIFIQUE ET TECHNIQUE / SCIENTIFIC AND TECHNICAL DESCRIPTION

2.1. ÉTAT DE L'ART / BACKGROUND, STATE OF ART

If energy efficiency has always been a concern in the design of hardware, it was in the past considered more like a problem of engineering or confined to specific areas: for example, in sensor ad-hoc networks energy aware routing or light cryptographic protocols have been proposed to save the limited battery of the devices. Recently, with the very sharp growth of network traffic and the increase of energy cost, the pressure for energy aware network algorithms has appeared. This area of research hence is at early stage of deployment. Nevertheless, it has already drawn the attention of different entities of the networking community.

Very recently, energy efficiency has been added to the **scope of interests of major conferences** like Infocom 2009 (Power Control & Management) or ONDM 2009 (Energy efficiency in optical networks). A new workshop, GreenComm'09, triggered by the **network operators** who want to reduce energy cost, has been proposed ([1]) for 2009.

The **router manufacturers** also show interests these last months in the study of green networks. As a matter of fact, under the pressure of rising energy costs and increasingly rigid environmental standards, governments and corporations around the world are tightening energy and emission budgets, thus creating demand for new, energy-aware generations of telecom equipments. In a recent report from 2008 [3], employees of Juniper discusses the practical aspects of achieving and objectively measuring energy efficiency in the telecom world. In particular they discuss the ins and outs of different metrics for energy efficiency. In [6], Cisco shows how to reduce by a significant amount the energy and cooling consumption by creating an integrated platform of six disparate devices (routers, switches, wireless access points...).

The European Commission is estimating that by 2012 the energy consumption in the home will reach 50 TWh (terawatt hours), from basically 0 TWh in the year 2000. Of the 10% (electricity consumption) globally spent for telecommunication, already today 70% are spent in homes / offices and only 30% in the network / server farms. That means that energy consumed by the homes will be twice as large as the one consumed by networks to bring broadband into the homes. The operators may contribute to stem the increase of power consumption in the home by an intelligent control of residential energy from the network.

Recently networks have experienced a **very sharp evolution of their traffic** due to two parallel phenomena: a strong growth of the demand and the development of new activities. This new activities reshape the structure of the demand. For example, [9] reveals the properties of the distribution of requests across youtube videos pointing out the rapid evolution of viewer's focus and the sudden shifts in popularity. Similarly [10] observes the power-law, small-world, and scale-free properties of online social networks. They observe that the network contains a densely connected core of high-degree nodes. Hence, the traffic becomes essentially changing on one hand and more concentrated on some other nodes on

another hand. The demand for new highly dynamic routing algorithms and network designs, able to taking into account these new constraints, is a good opportunity to develop and implement energy aware solutions, which would be especially efficient in such a context. Better P2P distribution techniques and better use of caching would allow a more uniform demand of traffic and therefore a better efficiency.

A first "wave" of studies to measure and reduce the power consumption of computer systems has been done in the 90's with the **apparition of mobile computing**. Laptops, for example, have a very limited battery that has to be carefully managed to achieve longer battery life. The largest efforts were done by **hardware** manufacturers to find new processes to build better hardware (like Intel [15]...). One of the major advances was to define multiple power states for different devices, e.g. hard disks and to develop mechanisms to allow system software to control transitions between these states. Different models have then been proposed to choose the best times to switch between these states. Among many studies [11,14,13], the authors showed in [18] that decreasing the spin down delay time (spinning down a disk during long period of inactivity is a classic power reduction technique), from the 3-5 minutes of the industry to 2 seconds could double the benefit of this techniques.
[11] proposes a new efficient power management system based on a hard disk state model.

Note that this wave also included **network level** studies to find more **energy aware network protocols**. [19] for example, propose an innovative transport layer protocol capable of significantly reduce the power usage of the communicating device. The protocol selectively chooses short periods of time to suspend communications and shutdown the communication device. They show that they can reduce up to 80 % of the energy consumed by the communication, while not significantly increasing the delay. This can translate to a 8 % savings in the energy consumed by a laptop or 40 % for a PC.

In France, the national platform of the CNRS, Recap regroups teams working on sensor and self-organized networks. The teams involved are in particular, the LIP in Lyon, the LAAS in Toulouse, the LIFL in Lille and the LIP6 in Paris. One of the objectives of the platform is the design of efficient data communications in wireless sensor networks. One of the tasks here is to minimize the communication overhead (since bandwidth in wireless communication is typically limited) and power consumption by battery operated nodes. However, note that in most such studies for sensor networks, the goal is to maximize the lifetime of the node and note to try to minimize the overall energy consumption (and so the global cost) of the network, leading to noticeably different problems. As a matter of fact, in the later case which is the one which interests us, it would be for example possible to "sacrifice" some of the nodes (that will have a very large resource usage) for the benefit of the whole network.

2.2. OBJECTIFS ET CARACTÈRE AMBITIEUX/NOVATEUR DU PROJET / RATIONALE HIGHLIGHTING THE ORIGINALITY AND NOVELTY OF THE PROPOSAL

Scientific and technical objectives of the project:
The main goal of the project is to incorporate the constraint of energy efficiency in the design and operation of networks.
The detailed objectives are to:

- Model the energy consumption of building blocks of a network (routers, switches, end-host machines...).
- Find methods to design more energy efficient networks.
- Develop new algorithmic to operate networks, whether for routing in backbone networks or for scheduling in wireless networks.

Originality inside the team-project Mascotte:
Mascotte's research fields include network design and conception of algorithms for communications. Hence this project is definitely inside the main areas studied by the project and we count on the experience and knowledge of other members of the team to help us to be successful.

The technical methods to tackle this project will be the use of algorithmic methods, analysis of algorithms and optimisation techniques that are in the technical expertise of the project.
Including energy awareness in the design and algorithmic of networks is however a new area of research for Mascotte. More generally, research and development in these areas are still at an early stage and the space of potential solutions is far from being explored.

This project would allow a *renewal of the application domains* of the team. It will propose *new theoretical challenges* as well, like the optimization of non convex linear programs or proposing new combinatory tools for this problem.
We will set up experiments to study the consumption of the network components which will reinforce the simulation sub-group of the mascotte project.

Preliminary efforts have been started in this new direction:
- A relatively similar problem has been studied in the context of radio networks mainly initiated by H. Rivano in mascotte project. In these networks, the routers can be the users themselves and therefore have very limited batteries. In such networks, the problem is to find a routing that utilizes few network resources, in order to spare the batteries of the routers.
- Napoleao Nepomuceno has started his PhD inside Mascotte. He is collaborating with the company 3-Roam (http://www.3roam.com/) which proposes solutions to enhance wireless network transmissions. He is actually studying the energy consumption of antennas, which would be one of the parts of our experimental study.

Scientific and technical locks:
Among other difficult points, the first stage of the project (the study of the energy consumption of the different network components) will provide realistic cost functions for different devices. These functions have very little chance to have a classical shape for several reasons: preliminary results indicate that in a very intensive range of operation, a router increases more than linearly its consumption. Similarly, at the opposite of the spectrum, a router that forwards a very weak and sparse traffic would waste a large part of its resource. The difficulty that appears in these conditions is that most of the works in the literature assume a convex cost function that is easier to handle. Anyway, this leaves us without

recipes to solve our problems. This is why, we want to propose specific tools to solve these problems.
Hence, finding efficient routing policy for this kind of cost functions imply solving very challenging optimization problems. We plan on proposing diverse heuristics and approximate algorithms to find solutions close to optimal ones.

Final results:
The main criterion of success will be the scientific output of the project, represented by publications, presentations at conferences, but also by participating to the emergence and strengthening of the field at the national and European level. For example we intend in the 3 years to organize of workshop at the French level that would bring together the groups working in this thematic. Another outcome will be the dissemination of our ideas with industry, at least in 3ROAM. We now detail the results to be obtained for each task.

Expected results (and criteria of evaluation and success):
The expected results together with the criteria of evaluation in this project are the following:

(1) **Performance evaluation and Measurements.** We want to deduce from experiments on several network components a precise estimation of the energy consumption in function of the amount of traffic routed. These cost functions could be used by the community to introduce realistic parameters in their models. It would also be of interest for operators to design their networks, while being aware of the different trade-offs associated to the building blocks of their networks.

Criteria of evaluation:
- Existence of realistic cost functions for diverse network components.
- Make available these results for the community.
- Note that an other important points would be bringing together the French community working on similar topics by organizing a workshop and …

(2) Design energy aware network architectures.

Criteria of evaluation.
- Having analyzed the cost of different network topologies. A toy example would be to compare a star shaped topology with a topology with uniform number of neighbours for the nodes.
- Study how the development of new applications and devices (smartphones, streaming videos...) changes the traffic dynamics, making obsolete some existing network design and making crucial the redesign of network architectures.
- Propose improvements of existing topologies.
- The metric energy and cost should give good results.

(3) **Management of networks.** We will propose new tools and new algorithms to route traffic in a network so that all routers are in the good range of operation to use less energy.

Criteria of evaluation. There exist here clear metrics of success:

- How much energy is saved with these new routing policies?
- How much money is economized if network components wear less quickly?

Perpetuation of the project:

This project includes two newly hired permanent researchers who will take this subject as their main direction of research. This will begin a new subgroup of research, which fits in the expertise of Mascotte, while developing new directions of applications and technical challenges. With the strongly growing demand of traffic from new users and new usages (due, for example, to the spread of smartphones), and the new crucial and lively interest to more energy aware solutions in everyday life, it is very unlikely that these thematic of research would disappear in the near future.

After 3 years of project, the group will have gained enough maturity to build a new project within the context of the restructuration of the mascotte project which happens early in 2011 and where new projects will have to be created.

3. PROGRAMME SCIENTIFIQUE ET TECHNIQUE, ORGANISATION DU PROJET / SCIENTIFIC AND TECHNICAL PROGRAMME, PROJECT MANAGEMENT

3.1. PROGRAMME SCIENTIFIQUE ET STRUCTURATION DU PROJET / SCIENTIFIC PROGRAMME, SPECIFIC AIMS OF THE PROPOSAL

Scientific program and Structuration of the project.

The main objectives of this project are to *introduce and analyze energy-aware network design and management* in order to increase the life-span of telecommunication hardware and to reduce the energy consumption together with the electricity bill. Note that the members of the project will partly go on working on their current topics of interest but in integrating this new consideration in their work.

The project is decomposed into the following four main tasks:

- **Task 0: Coordination of the project and monitoring of technological development.** This area of research is in early stage of deployment. Therefore, an important part of the work is to continuously monitor the progresses made by the different research teams on the topic.

- **Task 1: Performance evaluation, Measurements.** In order to evaluate the energy utilization of a whole network, the power consumption of the different elements of the network, such as a router, has to be studied. This study will also be the basis to propose specific realistic cost functions for the network devices.

As said in the introduction, there are three main possibilities to reduce the energy consumption of a network: first, at hardware, secondly during network design, last using an energy-aware management of the network. We plan to work on the two last research domains, where we have already proved our competence. It corresponds to two tasks:

- **Task 2: Design of networks.** The power consumption of a network is strongly influenced by its topology. We plan to study several topologies and their influence on the power consumption. Also, where to place the servers and what is the optimal number of servers for a domain are interesting questions. For the design of the networks, we plan to use some of the results on the router power consumption found during Task 1.

- **Task 3: Management of networks.** This last task is of major importance when the network has already been designed and when we can play mostly only on the routing to save energy. The goal here will be to find energy-aware routing policies that take into account the new characteristics of traffic.

Methodology and theoretical tools.

To handle these tasks, we will use the main tools used by the researchers of the team:

- **A general modelling of the problem.** A first step to study this new problem will be to make a general modelling for several types of networks (e.g., wired/wifi) that will contains a comprehensive objective function and the known constraints on network devices, as routers.

- **The use of algorithmic tools and graph theory.** Before searching for efficient solutions, a prior study of the complexity of the problem has to be done (NP-hardness or polynomiality) with tools from algorithmic and graph theory.

- **Approximate algorithms, heuristics, and combinatorial optimisation.** In order to propose a valid solution for this problem, algorithms or approximate algorithms or heuristics will be developed. Then, integer linear programming is a methodology that allows testing the performance of the proposed algorithms to the optimal solutions.

- **Experimental validation of solutions and simulations.** Finally, the proposed algorithms will be simulated and compared to other proposed solutions in other to validate their performance according to several metrics.

The members of this project and the mascotte project have proven in several occasions their competitiveness for all the detailed points. Indeed, they represent the main pole of expertise of the team since more than ten years and are the basic tools used for most of their research.

3.2. COORDINATION DU PROJET / PROJECT MANAGEMENT

The coordination of the project is an important task of the project. This coordination will be facilitated as the actors of the project are working in the same Mascotte team of the same INRIA laboratory in Sophia Antipolis.

In order to make the coordination as efficient as possible, several resolutions have been made:

1. The team will meet every two weeks in order to evaluate the situation. During these meetings, a paper presenting the main evolutions in similar domains as the project will be described by one of the member of the project. This meeting will fulfil some of the objectives of the monitoring of the scientific deployment.
2. Napoleao Nepomuceno is working in the 3ROAM enterprise every week. Napoleao will working mostly on task 1, therefore some reports describing these days of work will be written and presented during the planned meeting.
3. As soon as the project will begin, a complete web site describing the project will be done. This web page will announce the planned work, the deliverables, the results, and the planned meetings.

The main tasks are relatively independent as one task is not blocking for obtaining results in the other tasks. Therefore, the work can be divided among the members of the team without any difficulties. The design and management task (tasks 2 and 3) will take into account the results obtained during the measurement task (task 1) especially given by the router's cost function. Anyway, the work can begin without the whole results obtained by the task 1, and therefore there is no blocking task.

3.3. DESCRIPTION DES TRAVAUX PAR TÂCHE / DETAILED DESCRIPTION OF THE WORK ORGANISED BY TASKS

3.3.1 TASK 0: COORDINATION AND MONITORING OF THE SCIENTIFIC DEPLOYMENT

Coordinator. Frederic Giroire

Participants. David Coudert, Frederic Giroire, Joanna Moulierac, Napoleao Nepomuceno

Main objectives.

This task will combine the coordination and the monitoring of the scientific deployment. The main area of the project is at early stage of deployment. It promised to give fruitful results that will interest the networking community and also the network operators. Therefore, it is a relatively new area of research that is plainly in the scope of the main interests of the society nowadays. We need to be aware of each new result published in related areas.

Detailed program.

This task will be persistent all along the project and will take place in different ways:

4. **Organization of a green Seminar every two weeks.** The aim of this seminar is to present newly published papers. When presenting new results in this field, the team will get a strong knowledge of the work presented by the *green* community.
5. **Writing of a survey.** No paper describing the related work has been written yet on this new area. We plan to submit such a survey within the first year of the project.
6. New Ideas and algorithms developed in the main research teams such as climate group.
7. Collaboration with other European teams with first the participation in the Green Workshop.

Contributions.

All the participants of the project will be implied in that task, but the more implied will be the permanent researchers. It is of major importance that all the team is aware of the new results in the main area of the project. Therefore, all the persons implied in the project will have the task to monitor new results in similar area.

3.3.2 TASK 1: PERFORMANCE EVALUATION, MEASUREMENTS

Coordinator. Joanna Moulierac

Participants. David Coudert, Frederic Giroire, Joanna Moulierac, Napoleao Nepomuceno

Main objectives.

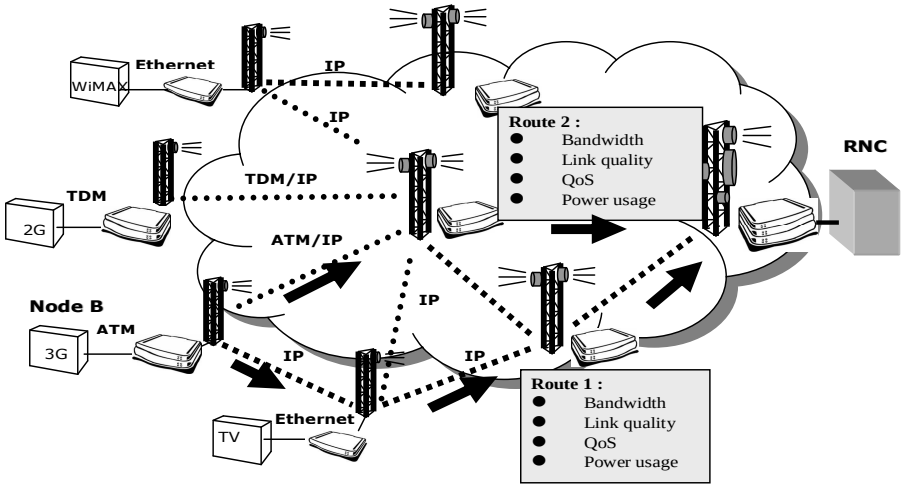
The main objectives of this task are to give an efficient energy function that characterizes the power consumption of network devices (e.g. routers or wireless antennas) and to give some quantified values on their performances.

Detailed program.

This task will begin as soon as the project begins, and will last 18 months. Napoleao Nepomuceno is already working on this study in the context of his Ph. D in the enterprise 3ROAM.

3ROAM has developed WLS Microwave Router which enables the deployment of multi-service wireless backhaul networks to carry traffic in cellular networks (2G, 2.5G and 3G), packet based networks (Wifi, WiMAX), video networks (DVB-H) or in fixed line networks (micro DSLAM). These wireless routers are highly configurable, the main configuration parameters being: transmitter power, modulation format, coding rate, interleaving depth, symbol rate. Moreover, unlike wired channels that are stationary and predictable, radio channels are dynamic in nature. Rain, snow, and hail can create large changes in the channel gain between transmitter and receiver. Modelling the radio channel has historically been one

of the most difficult parts of radio systems design, and is typically done in a statistical fashion, based on measurements made specifically for an intended communication system or spectrum allocation. Hence, the problem here is: given the configuration parameters, the context parameters (bandwidth; geography; environment; distance), and the performance parameters (energy consumption; throughput; latency; error rate) which measure the efficiency of the wireless communication link, we need to determine the configuration which optimizes a desired performance parameter (for example, minimize the energy consumption), while respecting some constraints/requirements over the others performance parameters (such as a minimum throughput and/or a maximum data error rate).



Napoleao Nepomuceno has started by testing the power consumption of a small simple installation: two antennas connected to two WLS Microwave Router and tested different configurations. The next step will be to run a large scale experiment on a deployed network with around 300 antennas connected to WLS routers. The overall consumption of the network will be tested for different configurations.

With the acquired experience in this challenging context of wireless links, we will then consider other network devices. Some equipment will be bought by the project and we plan to measure the energy consumption of desktop machines, laptops in different modes, routers, classical wireless switches. There is also a possibility of studying the INRIA gateway at the renater point in INRIA Sophia Antipolis. From these measurements, we hope to derive precise models of the resource consumption of the different building blocks of a network.

Methods, technical choices and pre-planned solutions.

The experience of our industrial contact 3ROAM to install and configure machines and networks with different types of technology will be of first importance. At a smaller scale, we plan to use the same kind of methodology to measure and select different sets of parameters. The core of our experiments will be to estimate the electricity consumption (in terms of Watts) of diverse network devices while varying their load. We will inject some traffic for

different configurations to get curves like consumption versus traffic. We hope to learn from these experiments the best range of operation of a router for example.

Note that Frederic Giroire was also involved in the collection and analysis of large-scale collections and analysis of network data during his postdoc in Intel Research in 2007. He helped to analyze the traffic of more than 300 corporate laptops. If the applications (network security among others) were not the same than in this proposal, this project gave him an experience to tackle practical experimentations in the context of networking.

Risks, alternative solutions and indicators of performance.

The main risks of this task are related to those of experimentation. Indeed, it is possible that after extensive simulations and experimentations, we are not able to deduce an efficient cost function for the routers. There are many parameters to take into account in order to make the experimentation and it will be difficult to isolate all of them to see exactly their impact on the results.

Therefore, in case of limited success of this task, we would use measurement studies of other groups that can be found in literature (see the related work section) as inputs for Task 2 and Task 3. We would also test theoretical cost functions of different shapes.

Contributions.

The main contribution will be to get realistic cost functions for different network devices. These cost functions would be of primary interest for our work during Tasks 2 and 3: for example, the knowledge of the trade-offs between different technologies (for example, wireless and wired) could be a help for operators to choose how to design their network; in the context of network management, the knowledge of the best ranges of operation of routers may be of great help to design efficient routing strategy. It would also be useful for the community as possible input for different network optimization studies.

3.3.3 TASK 2: DESIGN OF NETWORKS

Coordinator. Frederic Giroire

Participants. David Coudert, Frederic Giroire, Joanna Moulierac, Napoleao Nepomuceno

Main objectives.

The main objective of this task is to study the impact of the design of the networks on the power consumption of the whole network. Then, this study will give elements for an efficient design of network such as the topology or the placement of servers in the network.

This task aims to develop efficient tools for the design of backbone and access networks subject to predictable variation of traffic, with the extra constraints of minimizing the overall energy consumption. This includes the design of the network topology, but also the placement of data centers.

Detailed program.

This task will begin 6 months after the beginning of the project and will last 24 months. Part of the work done in Task 1 will be used in the task, in particular in the modelling of the power consumption.
During this task several issues will be addressed.

First, we will evaluate the impact of the traffic variations induced by new applications such as mobile Internet, on demand-TV, peer-to-peer,TVHD, or social networks, on the bandwidth needs.

- What is the impact on the demand of bandwidth and of its distribution in the network? As part of this effort, Frederic Giroire is actually working on estimating the strong variations of resource usage in P2P systems.
- What are the changes in topology induced by these new applications? Nowadays, most of the multimedia applications imply the connection to central data servers that sends the information, increasing the disposition of the traffic demand in a star shape. This tendency is also speeded by the development of cloud computing as well.

This will allow us to propose realistic traffic scenarios with both static traffic demands and evolving traffic demands (variations on minutes, hours and daily basis).

Using the different cost functions and the models of energy consumption developed during the first task, we will then study the impact of the *network topologies,* of the traffic demands and the routing algorithms on the need in energy. How the concentration induced by the development of a large number of new applications decreases the efficiency of networks in terms of resource usage?

- To start this study and quantify the effect of concentration, we will first consider different classical topologies. What are the results if the network is a mesh, a star, a random network? What is the consumption for general topology? What is the worse topology for the consumption?
- Then we will consider the more heterogeneous topologies of existing networks. In particular, we hope to be able to discover bad regions or bottlenecks that could lead to algorithmic methods to improve the existing design.

A concomitant question is to study the *impact of different network technologies*. What are the difference for similar routing algorithms between optical technology and wireless technology for example? This is of particular importance when a network operator wants to deploy a network in countries where there is no infrastructure.

When looking at different network topologies, the question of the *placement of the servers* in a network appears. As already stated, a large number of web applications rely on servers to be supported. Because of the very high (and rapidly increasing) load of these services, a crucial

question is where to put these servers to optimize the power consumption of the network. This placement will have a strong impact on the utilized energy and a more uniform positioning should lower the load on the network infrastructures.

An other way to modify traffic demand patterns without having to change the position in the network of large data centers is to use of *caching.* The idea is to replicate the commonly used data (meaning frequently used or demanded by a large number of users) and to place it in cache servers. A company like Akamai does that at a large scale today. We want to quantify the gain of such a policy in terms of energy consumption, as it leads to a more uniform distribution of the resources in the network. Other questions also are: what is the optimal level of replication of the information? Where to put the replicas in the network to obtain an optimal efficiency? How to associate and connect in an efficient manner a client to its server?

Risks, alternative solutions and indicators of performance.

Getting information the topologies of existing networks and on their changes due to the introduction of new applications would not be easy due to the confidentiality of part of this data. Contacts with different companies like 3ROAM, France Telecom (collaboration with Mascotte), the telecom company Sprint and Intel (visit and postdoc of Frederic Giroire) may help. In case this information is not available, we will still be able to study the impact of classical theoretical shape of networks (star, mesh,...).

Contributions.

We plan to contribute to the evaluation of the impact of new applications on the network resource usage (e.g. bandwidth), in particular Peer-to-Peer applications.

We plan to evaluate the impact of different network topologies (star, mesh, and existing topologies) on energy consumption.

We would like to help understand the trade-off between different choices of technology, for example Optical versus wifi.

We want to show how the placement of resources in the network (and also the replication of data in caches) could help reduce the heterogeneity in space and time of traffic demand, leading to a reduction of energy consumption.

3.3.4 TASK 3: MANAGEMENT OF NETWORKS

Coordinator. David Coudert

Participants. David Coudert, Frederic Giroire, Joanna Moulierac, Napoleao Nepomuceno, New Ph. D

Main objectives.

The main objective of this task is to study the management (mainly routing) of the network when it has been already designed.

Detailed program.

The cost function of the routers, given by the measurement task and the study for the design of the network will be taken into account for a general modelling of this problem.

A central question is what is the *impact of routing on the network energy consumption*. The cost functions derived during the measurement and modelling task (Task 1) have a very large chance to be strongly non linear. As a matter of fact, most of the devices use for example a very high amount of resources when they operate close to their maximal capacity. Hence, a routing putting a lot of load on some servers should not be efficient. Interestingly, if the infrastructure is used at a very low level, a uniform repartition of the load between routers should also not be the best policy: it could be better to operate some routers in their best range of operation and to ask the others for a very small contribution.
To tackle this problem of economical routing, we plan to model it using integer linear programming with non-linear, non-convex cost functions. Solving such kinds of problems is in most case very difficult.
So we will try to find efficient heuristics and approximation algorithms to find close to optimal routing policies.

Note that network management is a very large thematic and refers to the administration, maintenance, and provisioning of a network. We additionally plan to go on with our works on: the monitoring of the resources of a network, the support of load balancing and fault tolerance.

Methods, technical choices and pre-planned solutions.

A working group including David Coudert and Joanna Moulierac has already begun to propose a predetermined traffic routing in MPLS networks. The idea is to set up a routing that maintains a low number of forwarding entries in routers. In this case the energy of routers is spared as the look-up in the forwarding table is reduced.

During a 6 month visit in the laboratories of the telecom company, SPRINT (US), Frederic Giroire worked on proposing fault-tolerant routing for a backbone network. An algorithm was proposed based on Tabu Search Meta-heuristic, to optimally map the IP topology on a fibber infrastructure. The optimal mapping maximizes the robustness of a network by minimizing fibber sharing, while simultaneously maintaining ISP delay requirements. In addition the algorithm takes into consideration constraints that are faced by backbone administrators, such as a shortage of wavelengths or priorities among links. This experience in modelling (Integer Linear Formulation), optimization and heuristics to find new routing policies while keeping in mind practical considerations will be precious to propose solutions for efficient energy aware routing.

Risks, alternative solutions and indicators of performance.

The main risk is that we plan to tackle very hard optimization problem with non convex cost function. We are not sure to be able to determine optimal solutions in this context.
Nevertheless, we should be able to solve the problem in some particular cases: regular topologies, small sized networks...
We also plan to find approximations of the optimal solution for the general cases using heuristics in the cases where no exact solution can be found.

Contributions.

The main contribution will be to incorporate the overall energy consumption as criteria for the routing and to propose efficient routing policies.

Additional contributions could be:

- make the routing be aware of the type of traffic;
- The reduction of the size of the routing tables, leading to a decrease of the workload for the routers, in particular for the MPLS tunnels.

3.4. CALENDRIER DES TACHES, LIVRABLES ET JALONS / PLANNING OF TASKS, DELIVERABLES AND MILESTONES

The two following tables describe for each task:

- the period during which the task will take place,
- The deliverables and milestones.

Main TASKS	Persons	Year 1		Year 2		Year 3	
		6	12	18	24	30	36
Task 0: Coordination and monitoring of scientific deployment	F. GIROIRE D. COUDERT J. MOULIERAC						
Task 1: Performance evaluation	J. MOULIERAC N. NEPOMUCENO F. GIROIRE New PhD						
Task 2: Network design	F. GIROIRE D. COUDERT D. MAZAURIC New PhD						
Task 3: Network management	F. GIROIRE J. MOULIERAC New PhD						

Tableau 1 : Planning of the tasks all along the project

The four main tasks are not mutually dependent one from the others and the beginning of one task is not at a standstill if the results of the others tasks are not completely obtained.

Main Tasks – Deliverables and milestones	
Decomposition of the tasks	Dates and deadline
Task 0: Coordination and monitoring of technological deployment o Organization of a green seminar o Writing of a scientific survey on the related work o Collaboration with French/European teams	o 2 presentations per month o During the first year
Task 1: performance evaluation o 3ROAM Measures o Measures on other network devices o Design of a cost function of a router o Evaluation of the performance of a router **Main risk:** alea of experimentations. Difficulty to isolate the effects of the multiple configuration parameters of network devices.	o Months 1 to 10 o Months 6 to 12 o Months 10 to 18 o Months 12 to 18 Meeting every month. Napoleao goes to 3ROAM every week.
Task 2: Network design o Study of the impact of new applications on network topologies. o Placement of the servers in the network o Placement of resources (replication and caches). o Impact of the topology on the power consumption. o Trade-offs between different choices of technology, for example Optical versus wifi. **Main risk:** Getting information the topologies of existing networks and on their changes due to the introduction of new applications would not be easy due to the confidentiality of part of this data.	o Months 6 to 18 o Months 12 to 24 o Months 24 to 30 o Months 6 to 20 Meeting every month. Discussions one-to-one every week.
Task 3: Network management o Design of an efficient routing policies o Reduction of the number of forwarding states o Monitoring of the consumption of the network o Fault management **Main risk:** we plan to tackle very hard optimization problem with non convex cost functions. Optimal solutions will be hard to find.	o Months 12 to 36 o Months 12 to 24 o Months 24 to 30 o Months 30 to 36 Meeting every month. Discussions one-to-one every week.

Tableau 2 : Main deliverables and milestones of the project

4. STRATEGIE DE VALORISATION DES RESULTATS ET MODE DE PROTECTION ET D'EXPLOITATION DES RESULTATS / DATA MANAGEMENT, DATA SHARING, INTELLECTUAL PROPERTY AND RESULTS EXPLOITATION

In our field of research, the best manner to enhance the obtained results is to publish and present papers in prestigious conferences and journals. The relevant conferences to which we plan to make submission are: IEEE ICC, IEEE Infocom, IFIP Networking among others. The relevant journals to which we plan to make submission are: Elsevier Computer Communications, Elsevier Computer Networks, IEEE Networks

We also plan to participate to the emergence and strengthening of the field at the national and European level. For example we intend in the 3 years to organize of workshop at the French level that would bring together the groups working in this thematic. Another outcome will be the dissemination of our ideas with industry, at least in 3ROAM. At the international level, we envisage to be part of the first Green Workshop in 2009 in order to start, if possible, new collaborations in this domain.

5. ORGANISATION DU PROJET / CONSORTIUM ORGANISATION AND DESCRIPTION

5.1. DESCRIPTION, ADÉQUATION ET COMPLÉMENTARITÉ DES PARTICIPANTS / RELEVANCE AND COMPLEMENTARITY OF THE PARTNERS WITHIN THE CONSORTIUM

The two persons mainly involved in the project are Frédéric GIROIRE and Joanna MOULIERAC who will work on the project more than 80% of their research time. These two persons come from different horizons and they well complement each other.

Indeed, Frédéric GIROIRE has mainly worked on Networks, algorithmic and analytic combinatory of very large data sets.
Whereas Joanna MOULIERAC has mainly focused hers studies on more networking subjects such as multicasting MPLS networks, and monitoring of networks.

Therefore, these two profiles are completely adapted to the main tasks of the project. We will keep the main guideline the closest to the real world of telecommunications as possible with the profile of Joanna MOULIERAC and will gain strong theoretical and mathematical results with the profile of Frédéric GIROIRE. Also note the experience of Frédéric GIROIRE with practical thematic like network design, routing with practical constraints and network security. This experience was acquired during two visits in the research laboratories of two large international companies: a 6 month visit in the telecom company Sprint and a one year postdoc in Intel (see more in the next section).

Moreover, the two Ph.D students already involved in similar subjects will provide good work inside the project and there will be a great emulation between the three young Ph. D students working inside the project.

Finally, David COUDERT is a fully experienced researcher and will provide strong advices on the direction of the research by keeping a critical eye on the obtained results and by transmitting to the young researchers its main experience. Indeed, David COUDERT has been already involved plainly in an *ANR jeune chercheur* and has been several times involve in several European project such as COST 293 Graal (where he is the working group leader) or IST FET AEOLUS .

5.2. QUALIFICATION DU PORTEUR DU PROJET / QUALIFICATION OF THE PRINCIPAL INVESTIGATOR

Frederic Giroire, the principal investigator of the project, has tackled problems on topics directly related to the main tasks of this project. He used in different contexts most of the technical methods that are expected to be used.

- (Task 4) In the laboratories of the Telecom company SPRINT, he worked on the problematic off routing in backbone network while incorporating practical constraints like delay and priorities. This study led to two patents. This experience shows that the principal investigator succeeded in the past to adapt existing algorithms (e.g. Routing) to new practical constraints. This expertise will be of primary importance for the new challenges of designing efficient green routing protocols.

- (Task 3) He also worked on the conception of networks in two main occasions.
  - Again, while in Sprint, he proposed a method to exhibit the bottlenecks of networks and applied it to the continental Spring backbone network. It allows finding the places where an upgrade of the network will be the most beneficial.
  - Inside the project Mascotte, he worked on the design of on-board fault tolerant networks for telecommunication satellites of minimal size.

- (Task 2) During a postdoc in the laboratories of INTEL Research, he worked on analyzing network traffic from a collection of traces of hundreds of machines. This study leads to a patent disclosure. Then network traffic models were proposed in the context of anomaly detection. This knowledge of methods to handle practical measurement studies in the context of networking will be helpful to coordinate Task 2 during which data will be collected and models of energy conception will be proposed.

- (Task 1) His experience and previous work on the three tasks of the project will allow him to follow the advances of the different members of the group on the different thematics and to coordinate the efforts.

His knowledge of practical thematics, as proposed by industrials like Sprint, Intel, France Telecom and Alcatel Space, and of theoretical methods developed during his Ph.D. (optimization, graph theory, analysis of probabilistic algorithms) will allow him to be a bridge between the different tasks and different people.

5.3. QUALIFICATION, ROLE ET IMPLICATION DES PARTICIPANTS / CONTRIBUTION AND QUALIFICATION OF EACH PROJECT PARTICIPANT

	Nom Prénom	Emploi actuel	Unité de rattachement et Lieu	Personne. mois	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur	GIROIRE Frédéric	Chargé de Recherche CR2 CNRS	mascotte Project, INRIA Sophia Antipolis.	28.8	As a coordinator, will work on all 4 tasks. Theoretical competences in analysis of algorithms, combinatory and probability, optimization. Practical experience acquired inside large companies: network design and security, routing with practical constraint.
.Autres membres	MOULIERAC Joanna	Associate Professor	IUT Of Nice Mascotte Project, INRIA Sophia Antipolis	14.4	Will work on Tasks 0, 1 and 3. Strong knowledge of networking, in particular multicast and active monitoring. Theoretical competences in heuristics and analysis of performance by simulations.
	COUDERT David	Chargé de Recherche CR2 INRIA	mascotte Project, INRIA Sophia Antipolis.	7.2	Will mainly work on Task 2. Strong competences in modelling, algorithmic and optimization of networks. Strong knowledge of optical networks and routing.
	NEPOMUCENO Napoleao	PhD student	mascotte Project, INRIA Sophia Antipolis.	18	Will work on Task 1. Practical experience on network device and link measurements within 3ROAM. Theoretical knowledge of combinatorial optimization and hybrid metaheuristics.
	MAZAURIC Dorian	PhD student	mascotte Project, INRIA Sophia Antipolis.	18	Will work on Task 2. Knowledge of probabilistic modelling. Work on wireless networks.

6. JUSTIFICATION SCIENTIFIQUE DES MOYENS DEMANDES / SCIENTIFIC JUSTIFICATION OF REQUESTED BUDGET

1. Équipement / Equipment

2. Personnel / Staff

A Ph.D. student will be hired during the project in order to give additional strength to the project. He/She will be hired at the 1st of September 2009. The Ph. D thesis will last all along the 36 months of the project. Indeed, the two Ph. D students already active in the project, Napoleao Nepomuceno and Dorian Mazauric will enter respectively in their third year and second year of Ph.D. at the beginning of the ANR. Therefore, in order to initiate in good conditions the project and to finish it with enough people, it is of major importance to hire a Ph.D. student. During the first year of the project, 3 Ph.D. students will be active in the project, Napoleao Nepomuceno, Dorian Mazauric and the newly hired Ph.D. This will imply excellent conditions for the student to begin its Ph.D.

We ask also a reduction in teaching load for Joanna Moulierac for the three years which means a total budget of 30 k€ (10 k€ per year of discharge).

Therefore the total budget is:

- 100 k€ for the Ph. D. student which is decomposed by 30 k€ per year
- 30 k€ for the discharge which is decomposed by 10 k€ per year. 96 hours of discharge per year is envisaged.

3. Prestation de service externe / Subcontracting

4. Missions / Missions

We plan to make one or two international conferences per year per member of the group, which leads to 8 or 10 conferences a year, three summer school to provide a good formation to the young researchers of the project and moreover to invite one researcher in the team for three months.

The expected budget for the 36 months is:

8 national conferences	8*500 €	4 k€
6 conferences in Europe	6*1.5 k€	9 k€
6 conferences apart from Europe	6*2.5 k€	15 k€
3 summer schools	3*1 k€	3 k€
3 months for an invited researcher	3*3 k€	9 k€
Total:		40 k€

5. *Dépenses justifiées sur une procédure de facturation interne / Internal expenses*

6. *Autres dépenses de fonctionnement / Other expenses*

For our task of measurement of energy consumption of the network building blocks (task 1), we plan to buy:

6.1. DIFFERENT SMALL ELECTRONIC DEVICES (ROUTERS, ANTENNAS,...),

- Some equipment of measure,
- Three computers (workstations or laptops).

Each of these devices cost less than4 k€, therefore they not appear in the equipment budget.
The total estimated cost is 10 k€ which is decomposed in 7 k€ for the first year and 3 k€ for the second year.

7. ANNEXES

7.1. REFERENCES BIBLIOGRAPHIQUES / REFERENCES

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7.1.1 FREDERIC GIROIRE

Age: 30 (12 november 1978)

Actual situation: *Chargé de Recherche* CNRS (CR2)

Web page: *http://www-sop.inria.fr/members/Frederic.Giroire/*

Career path:

Since October 2008: CNRS CR2 at I3S, Sophia Antipolis.
2008: Postdoc of the University of Nice in the Mascotte Project.
2007: Postdoc in the laboratories of Intel Research, Berkeley US.
2003-2006: Ph.D. Student of the University Paris 6 in the ALGO Project of INRIA, Rocquencourt.
2002: Internship in the laboratories of the telecom company Sprint, US.
2000-2003: Magistere MMFAI of ENS, Paris.

Research interests:
Network design and network security, Analysis of large datasets, Conception and analysis of algorithms, Performance analysis of P2P storage systems.

Publication Summary: 2 publications in international journals, 6 in international conferences, 3 patents, 2 softwares.

Main publications:

(1) Order statistics and estimating cardinalities of massive data sets. F. Giroire. In *Discrete Applied Mathematics*, 2008.

(2) Minimal selectors and fault tolerant networks, O. Amini, F. Giroire, F. Huc, and S. Pérennes. To appear in *Networks*.
(3) The Cubicle vs. The Coffee Shop: Behavioral Modes in Enterprise End-Users. F. Giroire, J. Chandrashekar, G. Iannaccone, K. Papagiannaki, E. Schooler, N. Taft. Accepted to *Passive and Active Measurement conference (PAM)*, 2008. Published in the Springer Lecture Notes in Computer Science (LNCS) series. LNCS 4979, pp. 202-211.
(3) Estimating the number of active flows in a data stream over a sliding window. E. Fusy and F. Giroire. In David Appelgate, editor, Proceedings of the Ninth Workshop on Algorithm Engineering and Experiments and the Fourth Workshop on Analytic Algorithmics and Combinatorics, pages 223-231, 2007. SIAM Press.
(5) Increasing the Robustness of IP Backbones in the Absence of Optical Level Protection. F. Giroire, A. Nucci, N. Taft, C. Diot. In Proceedings of *IEEE INFOCOM*, San Francisco, USA, april 2003.

Patents:

Detecting Stealthy Botnets by tracking Destination Persistence.
F. Giroire, J. Chandrashekar, N. Taft, E. Schooler. and K. Papagiannaki.
Submitted disclosure (first part of patent process), January 2008.
Intel Corporation

Method and Systems for Identifying Optimal Mapping in a Network.
Frederic Giroire, Antonio Nucci, Nina Taft, Christophe Diot.
Filed on July 10, 2003.
Sprint Docket Number #2315/SPRI.104359.

Method and Systems for Correlating Practical Constraints in a Network.
Frederic Giroire, Antonio Nucci, Nina Taft, Christophe Diot.
Filed on July 10, 2003.
Sprint Docket Number #2315/SPRI.104359.

7.1.2 JOANNA MOULIERAC

Age: 27 (28 january 1981)

Actual situation: Associate professor University of Nice since September 2007

Web page: *http://www-sop.inria.fr/members/Joanna.Moulierac/*

Career path:
2007/2008: Teaching assistant at University of Rennes 1
2003-2006: Ph.D student at University of Rennes 1 (defense of Ph.D: nov. 2006)
1998-2003: Licence and Master of research at University of Montpellier 2.

Research interests: Multicast, reduction of the number of forwarding states, monitoring, MPLS networks.

Publication Summary: 2 international journals, 7 international conferences, 1 national conference.

Main publications:
(1) QoS multicast aggregation under multiple additive constraints. Naouel Ben Ali, Abdelfettah Belghith, Joanna Moulierac, Miklós Molnár. *Computer Communications Vol. 31 Issue 15. Elsevier* 2008.
(2) mQMA: multi-constrained QoS Multicast Aggregation. Naouel Ben Ali, Joanna Moulierac, Abdelfettah Belghith, Miklós Molnár. *IEEE Globecom* 2007
(3) On the number of MPLS LSP using Multicast Tree Aggregation. Joanna Moulierac, Alexandre Guitton, Miklós Molnár. *IEEE Globecom* 2006.
(4) Hierarchical Aggregation of Multicast Trees in Large Domains. Joanna Moulierac, Alexandre Guitton, Miklós Molnár. *Journal of Communications (JCM) Vol. 1 Issue 6. Academy Publisher* 2006.
(5) Multicast Tree Aggregation in Large Domains. Joanna Moulierac, Alexandre Guitton, Miklós Molnár. *IFIP Networking* 2006, Coimbra, Portugal.

Prices, distinctions: Best Paper Award for the International conference ConTEL 2005.

Projects:

Part.	Nom de la personne participant au projet	Personne. mois	Intitulé de l'appel à projets Source de financement Montant attribué	Titre du projet	Nom du coordinateur	Date début & Date fin
N°	Joanna Moulierac	3	INRIA COLOR 2008	LARECO: label reduction of multipoint communications	Joanna Moulierac	01/2008 - 12/2008

7.1.3 DORIAN MAZAURIC

Actual situation: Associate Ph.D student in Mascotte, joint project I3S (CNRS/UNSA) INRIA Sophia Antipolis.

Web page: *http://www-sop.inria.fr/members/Dorian.Mazauric*

Career path:
2007-2008: Master of research at University of Nice Sophia Antipolis
2005-2008: Engineering School at University of Nice Sophia Antipolis.
2002-2005: Licence of Applied Mathematics at University of Nice Sophia Antipolis.

Research interests: Scheduling algorithms in wireless networks, graph searching, network reconfiguration.

Publication Summary: 2 international conferences, 1 national conference.

Main publications:
(1) Computing and updating the process number in trees. David Coudert, Florian Huc, Dorian Mazauric. OPODIS 2008, Luxor, Egypt.
(2) A distributed algorithm for computing and updating the process number of a forest. David Coudert, Florian Huc, Dorian Mazauric. DISC 2008, Arcachon, France.
(3) Algorithme générique pour les jeux de capture dans les arbres. David Coudert, Florian Huc, Dorian Mazauric. AlgoTel 2008, Saint-Malo, France.

7.1.4 NAPOLEAO NEPOMUCENO

Age: 28 (29 october 1980)

Actual situation: Ph.D student at Mascotte, joint project I3S (CNRS/UNSA) INRIA Sophia Antipolis.

Web page: *http://www-sop.inria.fr/members/Napoleao-Vieira.Nepomuceno/*

Career path:
2007-2008: PhD student at Université de Nice Sophia / Universidade Federal do Ceará
2003-2006: Master Program in Applied Informatics at Universidade de Fortaleza, Brazil
1998-2002: Bachelor Program in Informatics at Universidade de Fortaleza, Brazil
1998-2002: Bachelor Program in Administration at Universidade Federal do Ceará, Brazil

Research interests: Combinatorial Optimization, Hybrid Metaheuristics, Wireless Communications.

Publication Summary: 1 book chapter, 3 in international conferences, 2 in national conferences.

Main publications:

(1) Scalability Analysis of a Novel Integer Programming Model to Deal with Energy Consumption in Heterogeneous Wireless Sensor Networks. A. Aguiar, P.R. Pinheiro, A.L.V. Coelho, N. Nepomuceno, Á. Neto, and R.P.P. Cunha. *Communications in Computer and Information Science Vol. 14, pages 11-20, Springer* 2008.
(2) A Hybrid Optimization Framework for Cutting and Packing Problems: Case Study on Constrained 2D Non-guillotine Cutting. N. Nepomuceno, P.R. Pinheiro, and A.L.V. Coelho. *Studies in Computational Intelligence Vol. 153, chapter 6, pages 87-99. Springer* 2008.
(3) Tackling the Container Loading Problem: A Hybrid Approach Based on Integer Linear Programming and Genetic Algorithms. N. Nepomuceno, P.R. Pinheiro, and A.L.V. Coelho. *EVOCOP 2007, Lecture Notes in Computer Science Vol. 4446, pages 154-165. Springer* 2007.

(4) Combining Metaheuristics and Integer Linear Programming: A Hybrid Methodology Applied to the Container Loading Problem. N. Nepomuceno, P.R. Pinheiro, and A.L.V. Coelho. *CTD 2007, Anais do XXVII Congresso da Sociedade Brasileira de Computação, pages 2028 - 2032, Rio de Janeiro,* 2007.
(5) Metaheurística e Programação Linear Inteira: Um Algoritmo Híbrido para o Problema de Carregamento de Contêineres. N. Nepomuceno, P.R. Pinheiro, and A.L.V. Coelho. *CLAIO 2006, Proc. of Congreso Latino-Iberoamericano de Investigación Operativa, Montevideo,* 2006 *(in Portuguese).*

Prices, distinctions: 10 best Master's Thesis in Computer Science, Brazil (XX Thesis and Dissertation Contest - CTD 2007), Brazilian Computer Society.

7.2. IMPLICATION DES PERSONNES DANS D'AUTRES CONTRATS / INVOLVEMENT OF PROJECT PARTICPANTS TO OTHER GRANTS, CONTRACTS, ETC...

Part.	Nom de la personne participant au projet	Personne. mois	Intitulé de l'appel à projets Source de financement Montant attribué	Titre du projet	Nom du coordinateur	Date début & Date fin
N°	David Coudert		ESF Research Networking Programmes	Mathematics for the Design and Management of Sustainable Communication Networks (SustainNETCOM)	Jose Luis Marzo (Univ. Girona, Spain), Arie Koster (Univ. Warwick, United Kingdom) and Alberto Marchetti (Univ. Roma La Sapienza, Italy)	01/2010-12/2014
N°	David Coudert	2 mois par an	ANR Blanc	AGAPE : Algorithmes de graphes à parametres fixes et exponentiels	Frédéric Havet	09/2009-09/2013