Activity Report 2012

Team FUN

self-organizing Future Ubiquitous Network

RESEARCH CENTER
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THEME
Networks and Telecommunications

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Team FUN

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2. Overall Objectives

2.1. Introduction

Context.

The Internet of Things [40] is a large concept with multiple definitions. However, the main concepts are the same in every vision and could be summed up as follows: *Imagine a world where every object has the capacity to communicate with its environment. Everything can be both analogue and digitally approached - reformulates our relationship with objects - things - as well as the objects themselves. Any object relates not only to you, but also to other objects, relations or values in a database. In this world, you are no longer alone, anywhere.* (Internet of Things council).

Future Ubiquitous Networks (FUN) are part of the Internet of Things. They are composed of tens to thousands heterogeneous hardware-constrained devices that interact with our environment and the physical world. These devices have limited resources in terms of storage and computing capacities and energy. They communicate through unreliable and unpredictable short-range wireless links and run on batteries that are not envisaged to be changed in current systems since generally deployed in hostile environments. Providing CPNs with energy saving protocols is thus a key issue. Due to these specific features, any centralized control is not conceivable, the new generation of CPNs must be autonomous, be self-organized and dynamically adapt to their environment. We will refer to this new generation of CPNs as SCyNets . The devices that compose CPNs can be sensors, small robots, RFID readers or tags.

Objects or things can now communicate with their environment through the use for instance of an RFID (Radio Frequency IDentification) tag that provides them a unique identifier (ID) and a way to communicate through radio waves.

In the case of a simple passive **RFID tag**, the thing only embeds a tag equipped with an antenna and some memory. To communicate, it needs to be powered by the electromagnetic field of an RFID reader. This reader may then broadcast the information read on tag over a network.

When this tag is equipped with a battery, it is now able to communicate with nearby things similar to itself that may relay its message. Tags can also be equipped with additional capacity and sensors (for light, temperature, etc...). The Internet of Things can thus now refer to a **wireless sensor** network in which each sensor sends the data it collects over its environment and then sends it to a sink, *i.e.* a special sensor node able to analyze those data. In every case, RFID tags or sensor nodes can **be moved unexpectedly** like hold by moving things or animals. We speak then about **'*undergone* mobility'**.

So far, things can thus communicate information about their environment. But when the capacity of sensors is extended even further, they can also act on their environment (for instance, the detection of an event (fire) may trigger an action like switching the light or fire hoses on). Sensor nodes become **actuators**. When this extended capacity is the faculty to move, actuators are also referred as actors or robots. In this latter case, the mobility is computed on purpose, we then speak about **'*controlled* mobility'**. Actuators are not moved but move by themselves.

The FUN research group aims to focus on self-organizing techniques for these heterogeneous Future Ubiquitous Networks (FUNs). FUNs need various self-organization techniques to work properly. Self-organization encompasses neighbor discovery (which what other devices a sensor/actuator can communicate directly?), communication, self-deployment, self-localization, activity scheduling (when to wake up, when to send data to save energy without being detrimental to the well behavior of the network, etc)...

Solutions provided by FUN should facilitate the use of FUNs and rub away heterogeneity and difficulties. These techniques should be **scalable**, **energy-aware**, **standard-compliant**, should manage undergone **mobility** and take advantage of controlled mobility when available. Solutions provided by FUN will consider vagaries of the realistic wireless environment by integrating cross-layer techniques in their design.

Motivation. To date, many self-organizing techniques for wireless sensor networks and mobile ad hoc networks arise in the literature and also from the POPS research group. Some of them are very efficient for routing [41], [39], discovering neighborhood [48], [47], scheduling activity and coverage [44], localizing [50], [38], etc. Nevertheless, to the best of our knowledge, most of them **have not been validated by experimentation**, only by simulation and thus cannot consider the real impact of the wireless links and real **node mobility** in different environments. In addition, some of them rely on assumptions that are known not to be true in realistic networks such as the fact that the transmission range of a node is a perfect disk. Other may perform well only when nodes are static. None of them considers to **take advantage of controlled mobility** to enhance performances. Similarly, many propositions arise regarding self-organization in RFID networks, mainly at the middleware level [51], [43] and at the MAC layer level [46]. Although these latter propositions are generally experimented, they are validated only in static environments with very few tags and readers. To fit realistic features, such algorithms should also be evaluated with regards to scalability and mobility.

RFID and sensor/actor technologies **have not been merged**. Though, RFID readers may now be mobile and communicate in a wireless peer-to-peer manner either with other RFID readers or wireless sensor nodes and all belong to the same network. This implies a study of the standards to allow inter-dependencies in a transparent manner. Although such works have been initiated inside EPC Global working groups, research actions remain scarce.

FUN research group aims at **filling this scientific gap** by proposing self-stabilizing solutions, considering vagaries of wireless links, node mobility and heterogeneity of nodes in compliance with current standards. Validation by experimentation is mandatory to prove the effectiveness of proposed techniques in realistic environments.

FUN will investigate new protocols and communication paradigms that allow the **transparent merging** of technologies. Objects and events might interconnect while **respecting on-going standards** and building an autonomic and smart network while being compliant with hardware resources and environment. FUN expects to rub away the difficulty of use and programmability of such networks by unifying the different technologies. In addition, FUN does not only expect to validate the proposed solutions through experimentation but also to learn from these experiments and from the observation of the impact of the wireless environment to take these features into consideration in the design of future solutions.

2.2. Highlights of the Year

The DECARTE funding project received the European RFID Award in March 2012 by RFID European Lab of ESCP Europe.

3. Scientific Foundations

3.1. Introduction

The research area of FUN research group is represented in Figure 1. FUN research group will address every item of Figure 1 starting from the highest level of the figure, *i.e.* in area of homogeneous FUNs to the lowest one. Going down brings more applications and more issues to solve. Results achieved in the upper levels can be re-used in the lower ones. Current networks encountered nowadays are the ones at the higher level, without any interaction between them. In addition, solutions provided for such networks are rarely directly applicable in realistic networks because of the impact of the wireless medium.

FUN research group intends to fill the scientific gap and extend research performed in the area of wireless sensor and actor networks and RFID systems in two directions that are complementary and should be performed in parallel:

- **From theory to experimentation and reciprocally** On one hand, FUN research group intends to investigate new self-organization techniques for these future networks that take into account realistic parameters, emphasizing experimentation and considering mobility.
- **Towards heterogeneous FUNs** On the other hand, FUN research group intends to investigate techniques to allow heterogeneous FUNs to work together in a transparent way for the user. Indeed, new applications integrating several of these components are very much in demand (i.e. smart building) and thus these different technologies need to cooperate.

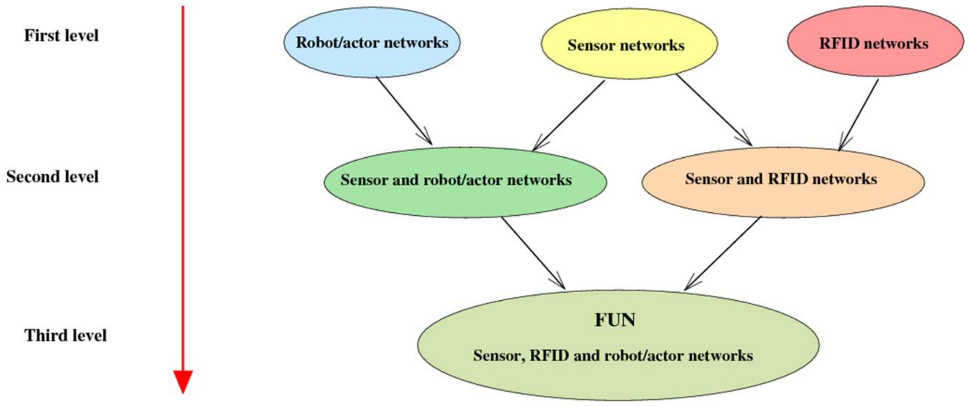

Figure 1. Panorama of FUN.

3.2. From theory to experimentation and reciprocally

Nowadays, even if some powerful and efficient propositions arise in the literature for each of these networks, very few are validated by experimentations. And even when this is the case, no lesson is learnt from it to improve the algorithms. FUN research group needs to study the limits of current assumptions in realistic and mobile environments.

Solutions provided by the FUN research group will mainly be algorithmic. These solutions will first be studied theoretically, principally by using stochastic geometry (like in [47]) or self-stabilization [49] tools in order to derive algorithm behavior in ideal environment. Theory is not an end in itself but only a tool to help in the characterization of the solution in the ideal world. For instance, stochastic geometry will allow quantifying changes in neighborhood or number of hops in a routing path. Self-stabilization will allow measuring stabilization times.

Those same solutions will then be confronted to realistic environments and their 'real' behavior will be analyzed and compared to the expected ones. Comparing theory, simulation and experimentation will allow better measuring the influence of a realistic environment. From this and from the analysis of the information really available for nodes, FUN research group will investigate some means either to counterbalance these effects or to take advantage of them. New solutions provided by the FUN research group will take into consideration the vagaries of a realistic wireless environment and the node mobility. New protocols will take as inputs environmental data (as signal strength or node velocity/position, etc) and node characteristics (the node may have the ability to move in a controlled way) when available. FUN research group will thus adopt a **cross-layered** approach between hardware, physical environment, application requirements, self-organizing and routing techniques. For instance, FUN research group will study how the controlled node mobility can be exploited to enhance the network performance at lowest cost.

Solutions will follow the building process presented by Figure 2. Propositions will be analyzed not only theoretically and by simulation but also by experimentation to observe the impact of the realistic medium on the behavior of the algorithms. These observations should lead to the derivation of cross-layered models. Experimentation feedbacks will be re-injected in solution design in order to propose algorithms that best fit the environment, and so on till getting satisfactory behavior in both small and large scale environments. All this should be done in such a way that the resulting propositions fit the hardware characteristics (low memory, CPU and energy capacity) and easy to deploy to allow their use by non experts. Since solutions should take into account application requirements as well as hardware characteristics and environment, solutions should be generic enough and then able to self-configure to adapt their environment settings.

In order to achieve this experimental environments, the FUN research group will maintain its strong activity on platform deployment such as SensLAB [52], FIT and Aspire [42]. Next steps will be to experiment not only on testbeds but also on real use cases. These latter will be given through different collaborations.

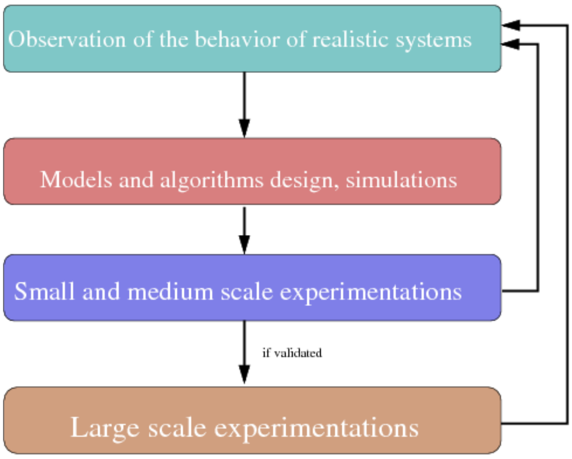

Figure 2. Methodology applied in the FUN research group.

FUN research group will investigate self-organizing techniques for FUNs by providing cross-layered solutions that integrate in their design the adaptability to the realistic environment features. Every solution will be validated with regards to specific application requirements and in realistic environments.

Facing the medium instability. The behavior of wireless propagation is very depending of the surrounding environment (in-door vs outdoor, night vs day, etc) and is very instable. Many experiments in different environment settings should be conducted. Experiment platforms such as SensLAB, FIT, our wifiBot as robots and actuators and our RFID devices will be used offering ways to experiment easily and quickly in different environments but might not be sufficient to experiment every environment.

Adaptability and flexibility. Since from one application to another one, requirements and environments are different, solutions provided by FUN research group should be **generic** enough and **self-adapt** to their environment. Algorithm design and validation should also take into account the targeted applications brought for instance by our industrial partners like Etineo. All solution designs should keep in mind the devices constrained capacities. Solutions should consume low resources in terms of memory, processor and energy to provide better performances and scale. All should be self-adaptive.

FUN research group will try to take advantage of some observed features that could first be seen as drawbacks. For instance, the broadcast nature of wireless networks is first an inconvenient since the use of a link between two nodes inhibits every other communication in the same transmission area. But algorithms should exploit that feature to derive new behaviors and a node blocked by another transmission should overhear it to get more information and maybe to limit the overall information to store in the network or overhead communication.

3.3. Towards unified heterogeneous FUNs

The second main direction to be followed by the FUN research group is to merge networks from the upper layer in Fig. 1 into networks from the lowest level. Indeed, nowadays, these networks are still considered as separated issues. But considering mixed networks bring new opportunities. Indeed, robots can deploy, replace, compensate sensor nodes. They also can collect periodically their data, which avoids some long and multi-hop communications between sensor nodes and thus preserving their resources. Robots can also perform many additional tasks to enhance network performance like positioning themselves on strategic points to ensure area coverage or reduce routing path lengths. Similarly, coupling sensors and RFID tags also brings new opportunities that are more and more in-demand from the industrial side. Indeed, an RFID reader may be a sensor in a wireless sensor network and data hold by RFID tags and collected by readers might need to be reported to a sink. This will allow new applications and possibilities such as the localization of a tagged object in an environment covered by sensors.

When at last all components are gathered, this leads us to a new era in which every object is autonomous. Let's consider for instance a smart home equipped with sensors and RFID reader. An event triggered by a sensor (*i.e.* an increase of the temperature) or a RFID reader (*i.e.* detection of a tag hold by a person) will trigger actions from actuators (*i.e.* lowering of stores, door opening). Possibilities are huge. But with all these new opportunities come new technological issues with other constraints. Every entity is considered as an object possibly mobile which should be dynamically identified and controlled. To support this dynamics, protocols should be localized and distributed. Model derived from experiment observations should be unified to fit all these classes of devices.

FUN research group will investigate new protocols and communication paradigms that allow the transparent merging of technologies. Objects and events might interconnect while respecting on-going standards and building an autonomic and smart network while being compliant with hardware resources and environment.

Technologies such as wireless sensors, wireless robots/actuators and RFID tags/ readers, although presenting many common points are still part of different disciplines that have evolved in parallel ways. Every branch is at different maturity levels and has developed its own standards. Nevertheless, making all these devices part of a single unified network leverages technological issues (partly addressed in the former objective) but also regarding to on-going standards and data formatting. FUN research group will have to study current standards of every area in order to propose compliant solutions. Such works have been initiated in the POPS research group in the framework of the FP7 ASPIRE project. Members of FUN research group intend to continue and enlarge these works.

Todays' EPCGlobal compliant RFID readers must comply to some rules and be configurable through an ALE [45]. While a fixed and connected RFID reader is easily configurable, configuring remotely a mobile RFID reader might be very difficult since it implies to first locate it and then send configuration data through a wireless dynamic network. FUN research group will investigate some tools that make the configuration easy and transparent for the user. This remote configuration of mobile readers through the network should consider application requirements and network and reader characteristics to choose the best trade-off relative to the software part embedded in the reader. The biggest part embedded, the lowest bandwidth overhead (data can be filtered and aggregated in the reader) and the greater mobility (readers are still fully operational even when disconnected) but the more difficult to set up and the more powerful readers. All these aspects will be studied within the FUN research group.

4. Software

4.1. Distributed ONS

Participants: Nathalie Mitton, Roberto Quilez [correspondant].

This module implements a DHT-based Distributed EPC Global ONS issued from the ANR WINGS project and published in [30]. APP number: IDDN.FR.001.180033.000.S.P.2012.000.10000.

- Version: version 1

4.2. GOLIATH 1.0

Participants: Fadila Khadar [correspondant], Nathalie Mitton.

GOLIATH (Generic Optimized LIghtweight communication stack for Ambient TecHnologies) is a full protocol stack for wireless sensor networks.

See also the web page https://gforge.inria.fr/projects/goliath/.

4.3. Linear variable energy module for WSNET.

Participants: Tony Ducrocq [correspondant], Nathalie Mitton.

This module is to be integrated in the WSNET event-based simulator for wireless networks. It implements a Linear transmission variable energy module for WSNET.

- Version: 1.0

5. New Results

5.1. Routing in FUN

Participants: Nicolas Gouvy, Xu Li, Nathalie Mitton.

Wireless sensor and actuator/robot networks need some routing mechanisms to ensure that data travel the network to the sink with some guarantees. The FUN research group has investigated different geographic routing paradigms. It first has considered a static network in which the routing either enhances the energy cost [22], [10], balances the load over nodes [21], [8] or respects traffic priorities [18].

A more complex routing paradigm has been proposed in [25] for k-anycasting. In k-anycasting, a sensor wants to report event information to any k sinks in the network. This is important to gain in reliability and efficiency in wireless sensor and actor networks. In this paper, we describe KanGuRou, the first position-based energy efficient k-anycast routing which guarantees the packet delivery to k sinks as long as the connected component that contains s also contains sufficient number of sinks. A node s running KanGuRou first computes a tree including k sinks among the M available ones, with weight as low as possible. If this tree has $m \geq 1$ edges originated at node s, s duplicates the message m times and runs m times KanGuRou over a subset of defined sinks. Simulation results show that KanGuRou allows up to 62% of energy saving compared to plain anycasting.

We then assumed that the sink that collects data is actually mobile and travels the network. Sensor nodes need thus to update the position of the sink in a smart fashion in order to limit the overhead generated by this update. In [9], we propose a novel localized Integrated Location Service and Routing (ILSR) scheme, based on the geographic routing protocol GFG, for data communications from sensors to a mobile sink in wireless sensor networks. The objective is to enable each sensor to maintain a slow-varying routing next hop to the sink rather than the precise knowledge of quick-varying sink position. In ILSR, sink updates location to neighboring sensors after or before a link breaks and whenever a link creation is observed. Location update relies on flooding, restricted within necessary area, where sensors experience (next hop) change in GFG routing to the sink. Dedicated location update message is additionally routed to selected nodes for prevention of routing failure. Considering both unpredictable and predictable (controllable) sink mobility, we present two versions. We prove that both of them guarantee delivery in a connected network modeled as unit disk graph. ILSR is the first localized protocol that has this property. We further propose to reduce message cost, without jeopardizing this property, by dynamically controlling the level of location update. A few add-on techniques are as well suggested to enhance the algorithm performance. We compare ILSR with an existing competing algorithm through simulation. It is observed that ILSR generates routes close to shortest paths at dramatically lower (90% lower) message cost.

When the network is composed of mobile sensors that have the faculty to control their mobility, this property can be exploited to enhance routing performance. In [3], we are interested in energy-aware routing algorithms that explicitly take advantage of node mobility to improve energy consumption of computed paths. Mobility is a two-sword edge however. Moving a node may render the network disconnected and results in early termination of information delivery. To mitigate these problems, we propose a family of routing algorithm called CoMNet (Connectivity preservation Mobile routing protocols for actuator and sensor NETworks), that uses local information and modifies the network topology to support resource efficient transmissions. Our extensive simulations show that CoMNet has high energetic performance improvement compared to existing routing algorithms. More importantly, we show that CoMNet guarantees network connectivity and efficient resource consumption.

5.2. Self-organization

Participants: Tony Ducrocq, Xu Li, Nathalie Mitton.

Self-organization encompasses several mechanisms [35]. This year, the FUN research group contributes to some of them such as neighbor discovery, localization, clustering and topology control in FUN.

5.2.1. Neighbor discovery

To perform routing or any specific task, a node needs to discover its neighbors. Hello protocol is the basic technique for neighborhood discovery in wireless ad hoc networks. It requires nodes to claim their existence/aliveness by periodic 'hello' messages. Central to a hello protocol is the determination of hello message transmission rate. No fixed optimal rate exists in the presence of node mobility. The rate should in fact adapt to it, high for high mobility and low for low mobility. In [31], we combine parameters of the neighborhood discovery (sending frequency of hello messages and changes in the neighborhood tables) and transmission range of the nodes. We present two algorithms that adapt transmission range of the sensors in a mobile WSN by still adapting frequency of hello messages in order to save energy and get accurate neighborhood tables. The first solution is based on the knowledge of turnover - change in the number of neighbors in consecutive iterations of the neighborhood discovery - used in conjunction with an adaptation of the message frequency and the transmission range, minimizing overall transmission cost of hello messages. The second solution is based on the computation of optimal range knowing the nodes' speed. Both algorithms are based on theoretical analysis. Results show that they are energy efficient and outperform solutions of the literature by maintaining high accuracy.

5.2.2. Topology control

Topology control is a tool for self-organizing wireless networks locally. It allows a node to consider only a subset of links/neighbors in order to later reduce computing and memory complexity. Topology control in wireless sensor networks is an important issue for scalability and energy efficiency. It is often based on graph reduction performed through the use of Gabriel Graph or Relative Neighborhood Graph. This graph reduction is usually based on geometric values.

In [7], we propose a radically new family of geometric graphs, i.e., Hypocomb, Reduced Hypocomb and Local Hypocomb for topology control. The first two are extracted from a complete graph; the last is extracted from a Unit Disk Graph (UDG). We analytically study their properties including connectivity, planarity and degree bound. All these graphs are connected (provided the original graph is connected) planar. Hypocomb has unbounded degree while Reduced Hypocomb and Local Hypocomb have maximum degree 6 and 8, respectively. To our knowledge, Local Hypocomb is the first strictly-localized, degree-bounded planar graph computed using merely 1-hop neighbor position information. We present a construction algorithm for these graphs and analyze its time complexity. Hypocomb family graphs are promising for wireless ad hoc networking. We report our numerical results on their average degree and their impact on FACE [39] routing. We discuss their potential applications and some open problems.

5.2.3. Localization

In mobile-beacon assisted sensor localization, beacon mobility scheduling aims to determine the best beacon trajectory so that each sensor receives sufficient beacon signals with minimum delay. We propose a novel DeteRministic bEAcon Mobility Scheduling (DREAMS) algorithm [6], without requiring any prior knowledge of the sensory field. In this algorithm, beacon trajectory is defined as the track of depth-first traversal (DFT) of the network graph, thus deterministic. The mobile beacon performs DFT under the instruction of nearby sensors on the fly. It moves from sensor to sensor in an intelligent heuristic manner according to RSS (Received Signal Strength)-based distance measurements. We prove that DREAMS guarantees full localization (every sensor is localized) when the measurements are noise-free. Then we suggest to apply node elimination and topology control (Local Minimum Spanning Tree) to shorten beacon tour and reduce delay. Through simulation we show that DREAMS guarantees full localization even with noisy distance measurements. We evaluate its performance on localization delay and communication overhead in comparison with a previously proposed static path based scheduling method.

5.2.4. Clustering

Clustering in wireless sensor networks is an efficient way to structure and organize the network. It aims to identify a subset of nodes within the network and bind it a leader (i.e. cluster-head). This latter becomes in charge of specific additional tasks like gathering data from all nodes in its cluster and sending them by using a longer range communication to a sink. As a consequence, a cluster-head exhausts its battery more quickly than regular nodes. In [14], we present BLAC, a novel Battery-Level Aware Clustering family of schemes. BLAC considers the battery-level combined with another metric to elect the cluster-head. It comes in four variants. The cluster-head role is taken alternately by each node to balance energy consumption. Due to the local nature of the algorithms, keeping the network stable is easier. BLAC aims to maximize the time with all nodes alive to satisfy application requirements. Simulation results show that BLAC improves the full network lifetime 3-time more than traditional clustering schemes by balancing energy consumption over nodes and still delivering high data percentage.

5.3. Self-deployment

Participants: Milan Erdelj, Xu Li, Karen Miranda, Enrico Natalizio, Tahiry Razafindralambo, Dimitris Zorbas.

Robot self-deployment may have different purposes. The FUN research group has addressed four of them that are *(i)* area coverage, *(ii)* barrier coverage, *(iii)* point of interest coverage and *(iv)* deployment for substitution networks.

5.3.1. Area coverage

In [1], with the focus on the self-organizing capabilities of nodes in WSRN, we propose a movement-assisted technique for nodes self-deployment. Specifically, we propose to use a neural network as a controller for nodes mobility and a genetic algorithm for the training of the neural network through reinforcement learning. This kind of scheme is extremely adaptive, since it can be easily modified in order to consider different objectives and QoS parameters. In fact, it is sufficient to consider a different kind of input for the neural network to aim for a different objective. All things considered, we propose a new method for programming a WSRN and we show practically how the technique works, when the coverage of the network is the QoS parameter to optimize. Simulation results show the flexibility and effectiveness of this approach even when the application scenario changes (e.g., by introducing physical obstacles).

In [4], we tackle the issue in a different way. We leverage prediction by exploiting temporal-spatial correlations among sensory data. The basic idea lies in that a sensor node can be turned off safely when its sensory information can be inferred through some prediction methods, like Bayesian inference. We adopt the concept of entropy in information theory to evaluate the information uncertainty about the region of interest (RoI). We formulate the problem as a minimum weight sub-modular set cover problem, which is known to be NP hard. To address this problem, an efficient centralized truncated greedy algorithm (TGA) is proposed. We prove the performance guarantee of TGA in terms of the ratio of aggregate weight obtained by TGA to that by the optimal algorithm. Considering the decentralization nature of WSNs, we further present a distributed version of TGA, denoted as DTGA, which can obtain the same solution as TGA. The implementation issues such as network connectivity and communication cost are extensively discussed. We perform real data experiments as well as simulations to demonstrate the advantage of DTGA over the only existing competing algorithm and the impacts of different parameters associated with data correlations on the network lifetime.

In [34], [13], we leverage some assumptions. One of the main operations in wireless sensor networks is the surveillance of a set of events (targets) that occur in the field. In practice, a node monitors an event accurately when it is located closer to it, while the opposite happens when the node is moving away from the target. This detection accuracy can be represented by a probabilistic distribution. Since the network nodes are usually randomly deployed, some of the events are monitored by a few nodes and others by many nodes. In applications where there is a need of a full coverage and of a minimum allowed detection accuracy, a single node may not be able to sufficiently cover an event by itself. In this case, two or more nodes are needed to collaborate and to cover a single target. Moreover, all the nodes must be connected with a base station that collects the monitoring data. In this paper we describe the problem of the minimum sampling quality, where an event must be sufficiently detected by the maximum possible amount of time. Since the probability of detecting a single target using randomly deployed static nodes is quite low, we present a localized algorithm based on mobile nodes. Our algorithm sacrifices a part of the energy of the nodes by moving them to a new location in order to satisfy the desired detection accuracy. It divides the monitoring process in rounds to extend the network lifetime, while it ensures connectivity with the base station. Furthermore, since the network lifetime is strongly related to the number of rounds, we propose two redeployment schemes that enhance the performance of our approach by balancing the number of sensors between densely covered areas and areas that are poorly covered. Finally, our evaluation results show an over 10 times improvement on the network lifetime compared to the case where the sensors are static. Our approaches, also, outperform a virtual forces algorithm when connectivity with the base station is required. The redeployment schemes present a good balance between network lifetime and convergence time.

5.3.2. Barrier coverage

Barrier coverage problem in emerging mobile sensor networks has been an interesting research issue. Existing solutions to this problem aim to decide one-time movement for individual sensors to construct as many barriers as possible, which may not work well when there are no sufficient sensors to form a single barrier. In [19], we try to achieve barrier coverage in sensor scarcity case by dynamic sensor patrolling. In specific, we design a periodic monitoring scheduling (PMS) algorithm in which each point along the barrier line is monitored periodically by mobile sensors. Based on the insight from PMS, we then propose a coordinated sensor patrolling (CSP) algorithm to further improve the barrier coverage, where each sensor's current movement strategy is decided based on the past intruder arrival information. By jointly exploiting sensor mobility and intruder arrival information, CSP is able to significantly enhance barrier coverage.We prove that the total distance that the sensors move during each time slot in CSP is the minimum. Considering the decentralized nature of mobile sensor networks, we further introduce two distributed versions of CSP: S-DCSP and G-DCSP. Through extensive simulations, we demonstrate that CSP has a desired barrier coverage performance and S-DCSP and G-DCSP have similar performance as that of CSP.

5.3.3. Point of Interest coverage

The coverage of Points of Interest (PoI) is a classical requirement in mobile wireless sensor applications. Optimizing the sensors self-deployment over a PoI while maintaining the connectivity between the sensors and the base station is thus a fundamental issue. This algorithm addresses the problem of autonomous deployment of mobile sensors that need to cover a predefined PoI with a connectivity constraint. In our algorithm [2], each sensor moves toward a PoI but has also to maintain the connectivity with a subset of its neighboring sensors that are part of the Relative Neighborhood Graph (RNG). The Relative Neighborhood Graph reduction is chosen so that global connectivity can be provided locally. Our deployment scheme minimizes the number of sensors used for connectivity thus increasing the number of monitoring sensors. Analytical results, simulation results and practical implementation are provided to show the efficiency of our algorithm.

We then extended this coverage to multiple points of interest in [15], [16]. Indeed, the problems of multiple PoI coverage, environment exploration and data report are still solved separately and there are no works that combine the aforementioned problems into a single deployment scheme. In this work, we have extended [2] to multiple PoI coverage and combined it to and environment exploration in order to capture the dynamics of the monitored area. We examine the performance of our scheme through extensive simulation campaigns.

5.3.4. Substitution networks

A substitution network is a temporary network that will be deployed to support a base network in trouble and help it to provide best service. [11], [24] present how the mobility of routers impacts the performance of a wireless substitution network. To that end, we simulate a scenario where a wireless router moves between three static nodes, a source and two destinations of UDP traffic. Specifically, our goal is to deploy or redeploy the mobile relays so that application-level requirements, such as data delivery or latency, are met. Our proposal for a mobile relay achieves these goals by using an adaptive approach to self-adjust their position based on local information. We obtain results on the performance of end-to-end delay, jitter, loss percentage, and throughput under such mobility pattern for the mobile relay. We show how the proposed solution is able to adapt to topology changes and to the evolution of the network characteristics through the usage of limited neighborhood knowledge.

5.4. MAC layer

Participant: Tahiry Razafindralambo.

Multihop wireless networks are used to provide Internet connectivity to the users and the level of performance and quality expected by these users are increasing. In order to meet these performance and quality requirements, wireless communications should be enhanced. Previous works from the literature show that the performance and quality provided by an IEEE 802.11-based multihop wireless network are far from optimal and that there exist different ways to increase the efficiency and the quality of service of such a network. Some studies show that using the medium state as a parameter to tune the behavior of an IEEE 802.11-based multihop network is an appropriate way to proceed. A station in a IEEE 802.11-based multihop wireless network senses the medium either busy or idle. The durations of idle periods and busy periods and their distributions have a clear impact on the network and nodes performance. The understanding of the relationship between these indicators, namely idle and busy periods, the network topology and the traffic, would give new insights to enhance the performance and quality of multihop wireless networks. Due to its multihop and distributed nature, the characterization of idle period durations is difficult in such a network. In [27], [26], we explore the characterization of idle period distribution by proposing a new analytical model and provides an application of this characterization with the design of an adaptive backoff algorithm based on idle periods.

5.5. Servicing

Participants: Xu Li, Kalypso Magklara, Nathalie Mitton, Tahiry Razafindralambo, Dimitris Zorbas.

Servicing wireless sensor networks include many primitives. It can range from cloud connection [12] to mobile IPv6 management [29] going through energy prediction [20] and launching mobile robots on request of a specific demand [5] or to reload sensors [23], [17].

5.5.1. Node reloading

A critical problem of wireless sensor networks is the network lifetime, due to the device's limited battery lifetime. The nodes are randomly deployed in the field and the system has no previous knowledge of their position. To tackle this problem, in [23], we use a mobile robot, that discovers the nodes around it and replaces the active nodes, whose energy is drained, by fully charged inactive nodes. We propose two localized algorithms, that can run on the robot and that decide, which nodes to replace. We simulate our algorithms and our findings show that all nodes that fail are replaced in a short period of time.

In [17] we focus on an emerging kind of cooperative networking system in which a small team of robotic agents lies at a base station. Their mission is to service an already-deployed WSN by periodically replacing all damaged sensors in the field with passive, spare ones so as to preserve the existing network coverage. This novel application scenario is here baptized as "multiple-carrier coverage repair" (MC2R) and modeled as a new generalization of the vehicle routing problem. A hybrid metaheuristic algorithm is put forward to derive nearly-optimal sensor replacement trajectories for the robotic fleet in a short running time. The composite scheme relies on a swarm of artificial fireflies in which each individual follows the exploratory principles featured by Harmony Search. Infeasible candidate solutions are gradually driven into feasibility under the influence of a weak Pareto dominance relationship. A repair heuristic is finally applied to yield a full-blown solution. To the best of our knowledge, our scheme is the first one in literature that tackles MC2R instances. Empirical results indicate that promising solutions can be achieved in a limited time span.

5.5.2. *Energy prediction*

One way to improve energy supply for sensor nodes is through ambient energy harvesting from solar, thermal or vibration energy sources coupled with rechargeable energy storage. Wireless sensors have to adapt to the stochastic nature of the energy harvesting sources. We are convinced that predicting the temporal availability of ambient energy resources is vital to plan the harvesting efficiency, optimum resource utilization and energy conservation within sensor nodes. In [20] we propose a novel two stage Autoregressive Weather conditioned Solar Energy Prediction (AWSEP) model which is characterized by low computational complexity and is used to accurately estimate the amount of solar energy that will be harvested in the near future in a particular region. Our algorithm re-learns the model parameters during the prediction processing situations where the prediction error becomes larger than a predefined prediction error threshold mainly because of the unreliable nature of outdoor solar energy sources caused by changes in weather conditions. The proposed AWSEP model performance is evaluated by varying energy harvesting source prediction intervals, sampling rates, trade-offs in prediction accuracy and computational costs using real solar datasets. We concluded that AWSEP algorithm is more accurate, has reduced computational complexity and memory utilization than other prediction schemes in literature. Our proposed algorithm can assist a node to automatically adapt to the changing weather conditions for effective power management and sensing task scheduling.

5.5.3. *Servicing sensor nodes*

Due to the robots' potential to unleash a wider set of networking means and thus augment the network performance, WSRNs have rapidly become a hot research area. In [5], we elaborate on WSRNs from two unique standpoints: robot task allocation and robot task fulfillment. The former deals with robots cooperatively deciding on the set of tasks to be individually carried out to achieve a desired goal; the latter enables robots to fulfill the assigned tasks through intelligent mobility scheduling.

5.6. Experimenting

Participants: Nathalie Mitton, Julien Vandaele.

One of the goal of the FUN research group is to validate through experimentations and to provide tools for this purpose. Therefore, the FIT platform is deployed, together with a set of tutorials [37]. Nevertheless, we are aware that using testbed platforms for validation is already a great step but it can not satisfy all needs. This is why we also investigate alternatives as emulation. In [28], [32] for instance, we propose a specifically designed experimental setup using a relatively small number of nodes forming a real one-hop neighborhood used to emulate any real WSN. The source node is a fixed sensor, and all other sensors are candidate forwarding neighbors towards a virtual destination. The source node achieves one forwarding step, then the virtual destination position and neighborhood are adjusted. The same source is used again to repeat the process. The main novelty is to spread available nodes regularly following a hexagonal pattern around the central node, used as the source, and selectively use subsets of the surrounding nodes at each step of the routing process to provide the desired density and achieve changes in configurations. Compared to real testbeds, our proposition has the advantages of emulating networks with any desired node distribution and densities, which may not be possible in a small scale implementation, and of unbounded scalability since we can emulate networks with an arbitrary number of nodes. Finally, our approach can emulate networks of various shapes, possibly with holes and obstacles. It can also emulate recovery mode in geographic routing, which appears impossible with any existing approach.

5.7. RFID middleware

Participants: Roberto Quilez, Nathalie Mitton.

The Object Naming System (ONS) is a central lookup service used in the EPCglobal network for retrieving location information about a specific Electronic Product Code (EPC). This centralized solution lacks scalability and fault tolerance and encounters some political issues. In [30], we present the design principles of a fully-distributed multi-root solution for ONS lookup service. In distributed systems, the problem of providing a scalable location service requires a dynamic mechanism to associate identification and location. We design, prototype, and evaluate PRONS, a DHT-based solution for the multi-root problem. We show that PRONS achieves significant performance levels while respecting a number of neutrality requirements.

5.8. VANET

Participants: Enrico Natalizio, Thierry Delot.

Today, thanks to vehicular networks, drivers may receive useful information produced or relayed by neighboring sensors or vehicles (e.g., the location of an available parking space, of a traffic congestion, etc.). In [33], we address the problem of providing assistance to the driver when no recent information has been received on his/her vehicle. Therefore, we present a cooperative scheme to aggregate, store and exchange these events in order to have an history of past events. This scheme is based on a dedicated spatio-temporal aggregation structure using Flajolet-Martin sketches and deployed on each vehicle. Contrary to existing approaches considering data aggregation in vehicular networks, our main goal here is not to save network bandwidth but rather to extract useful knowledge from previous observations. In this paper, we present our aggregation data structure, the associated exchange protocol and a set of experiments showing the effectiveness of our proposal.

In [36], we present a novel vehicular communication protocol, which aims to reduce the effect of broadcast storm problem in VANETs (Vehcular AdHoc NETworks). When the traffic density is above a certain value (e.g., when vehicles are in congested traffic scenarios), one of the most serious problems is the increase of packet collisions and medium contentions among vehicles which attempt to communicate. Our proposed technique, namely Selective Reliable Broadcast protocol (SRB), is intended to limit the number of packet transmissions, by means of opportunistically selecting neighboring nodes, acting as relay nodes. As a result, the number of forwarder vehicles is strongly reduced, while network performance is preserved. SRB belongs to the class of broadcast protocols, and exploits the traditional vehicular partitioning behavior to select forwarders. Each cluster is automatically detected as a zone of interest, whenever a vehicle is approaching, and packets will be forwarded only to selected vehicles, opportunistically elected as cluster-heads. In respect of traditional broadcast approaches, the main strengths of SRB are the efficiency of detecting clusters and selecting forwarders in a fast way, in order to limit the broadcast storm problem. Simulation results have been carried out both in urban and highway scenarios, in order to validate the effectiveness of SRB, in terms of cluster detection and reduction of number of selected forwarders.

6. Bilateral Contracts and Grants with Industry

6.1. Etineo Partnership

Participants: Roudy Dagher, Xu Li, Fadila Khadar, Nathalie Mitton [correspondant].

EtiPOPS will focus on portability and flexibility of GOLIATH on several hardwares and in different environments (indoor and outdoor) through the deployment of different applications such as geolocalization. In order to favor the portability, designed solutions in EtiPOPS will respect on-going communication standards which will allow a greater interoperability between heterogeneous hardwares.

6.2. France Telecom partnership

Participants: Nathalie Mitton, Enrico Natalizio, Tahiry Razafindralambo [correspondant], Dimitris Zorbas.

This collaboration aims to investigate rural networks and to deploy efficiently and dynamically such networks.

6.3. Noolitic partnership

Participants: Roudy Dagher, Nathalie Mitton [correspondant], Roberto Quilez.

This collaboration aims to set up a localization trial for localization of mobile object in a building based on wireless sensor networks. The idea is to deploy some landmarks (fix sensors) in places to be defined and to equip the mobile objects to other sensors. These sensors must be zigbee compliant for portability purposes.

6.4. Traxens partnership

Participants: Natale Guzzo, Nathalie Mitton [correspondant], Tahiry Razafindralambo.

This collaboration aims to set up a full protocol stack for TRAXENS's guideline.

7. Partnerships and Cooperations

7.1. International Initiatives

Tahiry Razafindralambo is researcher on leave at Inria Chile from Sept. 2012 to Aug. 2013 investigating *Integration of wireless sensor network deployed in mines into the Internet*.

7.2. Regional Initiatives

7.2.1. DECARTE

Participants: Nathalie Mitton [correspondant], David Simplot-Ryl.

Title: Developpement de Carton électronique

Type: FUI

Duration: November 2008 - Avril 2013

Coordinator: Cartonneries de Gondardennes

Others partners: Inria FUN IEMN CTP Cascades IER TagSys

Abstract: DECARTE studies the printing of an UHF RFID tag on packaging in order to reduce manufacturing costs.

7.2.2. Tracaverre

Participant: Nathalie Mitton [correspondant].

Title: Tracaverre

Type: FUI

Duration: November 2012 - Avril 2015

Coordinator: Saver Glass

Others partners: Inria FUN IEMN Courbon Camus La Grande Marque LIRIS DISP

Abstract: ___Tracaverre studies the use of RFID for traceability of prestigious bottles.___

7.2.3. IDC

Participants: Roudy Dagher, Nathalie Mitton [correspondant], David Simplot-Ryl.

Title: Intelligent Data Center

Type: IPER

Duration: November 2010 - June 2012

Coordinator: NooliTic

Others partners: Inria FUN CIV

Abstract: ___IDC studies wireless sensor network based solution to optimize the server monitoring in data centers. ___

7.3. National Initiatives

7.3.1. ANR

7.3.1.1. RESCUE

Participants: Milan Erdelj, Nathalie Mitton, Kalypso Magklara, Karen Miranda, Tahiry Razafindralambo [correspondant].

Title: Reseau Coordonne de substitution mobile

Type: VERSO

Duration: December 2010 - December 2013

Coordinator: Inria FUN

Other partners: LAAS UPMC France Telecom ENS Lyon

See also: ___http://rescue.lille.inria.fr/___

Abstract: ___In RESCUE, we propose to exploit the controlled mobility of mobile routers to help a base network in trouble provide a better service. The base network may be any access network or metropolitan network (including wired and wireless technologies). Troubles may come from an increase of unplanned traffic, a failure of an equipment, or a power outage.

When no backup networks are available, it would be interesting to deploy, for a limited time corresponding to the period of the problem (i.e., failure or traffic overload), a substitution network to help the base network keep providing services to users. In the RESCUE project, we will investigate both the underlying mechanisms and the deployment of a substitution network composed of a fleet of dirigible wireless mobile routers. Unlike many projects and other scientic works that consider mobility as a drawback, in RESCUE we use the controlled mobility of the substitution network to help the base network reduce contention or to create an alternative network in case of failure.

7.3.1.2. WINGS

Participants: Nathalie Mitton [correspondant], Roberto Quilez, David Simplot-Ryl.

Title: Widening Interoperability for Networking Global Supply Chains

Type: VERSO

Duration: November 2009 - March 2012

Coordinator: GS1

Other partners: Inria FUN UPMC France Telecom AFNIC GREYC

See also: __http://www.wings-project.fr/___

Abstract: ___This 2-year project focus on a proof-of-concept platform demonstrating the federated ONS model and the interaction with a prototype of Discovery Service. ___

7.3.1.3. F-Lab

Participants: Nathalie Mitton [correspondant], Priyanka Rawat, Tahiry Razafindralambo.

Title: Federating Computing Resources

Type: VERSO

Duration: November 2010 - November 2013

Coordinator: UPMC

Other partners: Inria DNet, Planete, FUN Thales ALU

See also: ___http://f-lab.fr/___

Abstract: ___The F-Lab project works towards enabling an open, general-purpose and sustainable large-scale shared experimental facility that fosters the emergence of the Future Internet. F-Lab builds on a leading prototype for such a facility: the OneLab federation of testbeds. F-Lab will enhance the OneLab federation model with the addition of SensLAB's unique sensor network and LTE-based cellular systems, and develop tools to conduct experiments on these enriched facilities. Project partners include some of France's top academic and industrial research institutions, working together to develop experimental facilities on the Future Internet. F-Lab presents an unique opportunity for the French community to play a stronger role in the design of federation systems; for the SensLAB testbed to reach an international visibility and use; and for the pioneering of testbeds based on LTE technology. ___

7.3.1.4. BinThatThinks

Participants: Tony Ducrocq, Nathalie Mitton [correspondant].

Title: BinThatThinks

Type: ECOTECH

Duration: November 2010 - November 2013

Coordinator: Inria ACES (Rennes)

Other partners: Etineo Veolia

See also: ___http://binthatthink.inria.fr/___

Abstract: ___ Efficient dust sorting is a main challenge for the current society. BinThatThinks is a research project that aims to propose a system that makes the collect and sorting easier through the use of RFID and sensors. ___

7.3.2. ADT

7.3.2.1. SenSas

Participants: Nathalie Mitton [correspondant], Lucie Jacquelin, Tahiry Razafindralambo, Julien Vandaele.

Title: Sensor Network Applications (SensAS)

Type: ADT

Duration: November 2010 - November 2014

Coordinator: Inria D-NET

Others partners: Inria Non-A Inria Planete Inria NECS Inria DEMAR Inria MADYNES Inria AMAZONE Inria SED

See also: ___http://sensas.gforge.inria.fr/___

Abstract: ___Sensas aims to propose mainly control science application based on wireless sensor and actuator network nodes provided from the work done around senslab and senstools projects.___

7.3.2.2. SensLille

Participants: Victor Corblin, Khalil Hammami, Nathalie Mitton [correspondant], Loic Schmidt, Julien Vandaele.

Title: SensLille

Type: ADT

Duration: November 2011 - November 2013

Coordinator: Inria FUN

Abstract: ___SensLille is an ADT that aims to improve SensLab Lille platform by offering new functionalities as the use of electric trains to experiment mobile nodes.___

7.3.2.3. MiAOU

Participants: Ibrahim Amadou, Rim Driss, Nathalie Mitton [correspondant], Loic Schmidt, Julien Vandaele.

Title: Middleware Application to Optimal Use (MiAOU)

Type: ADT

Duration: December 2012 - November 2014

Coordinator: Inria FUN

Abstract: ___Miaou is an ADT that aims to promote the AspireRFID middleware to a new level of manageability and usability.___

7.3.3. Equipements d'Excellence

7.3.3.1. FIT

Participants: Nathalie Mitton [correspondant], Anne-Sophie Tonneau, Tahiry Razafindralambo, Loic Schmidt, David Simplot-Ryl, Julien Vandaele.

Title: Future Internet of Things

Type: EquipEx

Duration: March 2010 - December 2019

Coordinator: UPMC

See also: ___http://fit-equipex.fr/___

Abstract: ___FIT (Future Internet of Things) aims to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. It will provide this facility with a set of complementary components that enable experimentation on innovative services for academic and industrial users. The project will give French Internet stakeholders a means to experiment on mobile wireless communications at the network and application layers thereby accelerating the design of advanced networking technologies for the Future Internet.

FIT is one of 52 winning projects from the first wave of the French Ministry of Higher Education and Research's "Equipements d'Excellence" (Equipex) research grant program. Coordinated by Professor Serge Fdida of UPMC Sorbonne Universités and running over a nine-year period, the project will benefit from a 5.8 million euro grant from the French government.___

7.4. European Initiatives

7.4.1. Collaborations in European Programs, except FP7

Program: ICT Labs

Project acronym: FiTTING

Project title: FiTTING

Duration: January 2012 - December 2012

Coordinator: UPMC

Other partners: Inria, IBBT, Fraunhoffer, University of Budapest

Abstract: The FITTING facility is about developing the tools needed to create the Future Internet of Things. The experimenters (both academic and industrial) who are developing this new technology require access to experimental platforms (testbeds) whey they can try out their ideas before releasing them to the general public. FITTING facilitates their innovation by federating Europe's next-generation testbeds.

7.5. International Initiatives

7.5.1. Participation In International Programs

Program: CoperLink

Project acronym: Palmares

Project title: Palmares

Duration: January 2012 - April 2013

Coordinator: Universita degli Studi Mediterranea, Italy

Other partners: Inria, Stellebosch University (South Africa)

Abstract: Internet of things, VANET and substitution networks.

7.6. International Research Visitors

7.6.1. Visits of International Scientists

Oswald Jumira (from June 2012 until July 2012)

Institution: Stellenbosch University (South Africa)

Essia Hamouda (from June 2012 until July 2012)

Institution: University of Riverside (USA)

Danping He (from August 2012 until October 2012)

Subject: Range and frequency adaptation in neighbor discovery in mobile wireless networks.

Institution: Universidad de Madrid (Spain)

Pr Ian Akyiliz (July 2012)

Institution: GeorgiaTech (USA)

7.6.1.1. Internships

Natale GUZZO (from May 2012 until Oct 2012)

Subject: Quality of Service and Energy Efficiency in Wireless Networks

Institution: Universita di Roma La Sapienza (Italy)

Kalypso Magklara (from Apr 2012 until Sep 2012)

Subject: Pickup and delivery problems in wireless sensor and actuator networks

Institution: University of Piraeus (Greece)

Jaco Du Toit (from Sept 2012 to Jan 2013)

Subject: Application of the Principles of Erasure Resilient Channel Coding Strategies in Distributed Wireless Network Environments

Institution: Stellenbosch University (South Africa)

Johan Pieterse (from Sept 2012 to Jan 2013)

Subject: Investigation of Handover Techniques in a IPv6 Mobile Wireless Network

Institution: Stellenbosch University (South Africa)

Rim Driss (from Apr 2012 to Sept 2012)

Subject: Analysis of the impact of error on geographic positions in neighbor discovery in wireless networks.

Institution: Université de Sfax (Tunisia)

7.6.2. Visits to International Teams

- Tahiry Razafindralambo is made available from Sept 1st 2012 to Aug 21 2013 at Universidad de Santiago, Chili.
- Nathalie Mitton visited for 2 weeks Stellebosch University (Aug-Sept 2012) in South Africa.

8. Dissemination

8.1. Scientific Animation

8.1.1. Conference organization

Program (co-)chairs

- Nathalie Mitton is/was program chair or co-program chair for iThings 2012, EPRA 2012 and AdHocNets 2012.

Program committee members

- Nathalie Mitton is/was in the Technical Program Committee (TPC) for LoGASN 2012, WPMC 2012, iThings 2012, WWASN 2012, CMC 2012.
- Tahiry Razafindralambo is/was a TPC member for BIONETICS 2012, ALGOTEL 2012, MSWIM 2012, DCOSS 2012, PE-WASUN 2012, MASS 2012.

8.1.2. Editorial activity

- Nathalie Mitton and Xu Li are editorial board members of AHSWN since 2011
- Nathalie Mitton is editorial board member of AdhocNetworks since 2012
- Xu Li is editorial board member of Parallel and Distributed Computing and Networks since 2010
- Xu Li is associate editor, European Transactions on Telecommunications since 2011
- Nathalie Mitton is guest editor for special issues in Eurasip journal (2012)
- Nathalie Mitton and Xu Li are guest editors of special issue in Springer PPNA (2012)
- Xu Li is guest editor of special issues in Elsevier's COMCOM, JCM and AHSWN (2011)

8.1.3. Misc

+ Nathalie Mitton is member of the ANR programme blanc SIMI3.
+ Nathalie Mitton is a member of the Inria COST-GTAI, Technological development committee (CDT) and Building User committee (CUB).

+ Tahiry Razafindralambo is a member of the Inria Lille Nord Europe Research Center committee and a member of CNU section 27 of Université de La Réunion (2012).

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Master : Tahiry Razafindralambo, Wireless networks, 40h eqTD, Université de la Réunion, France

Master : Nathalie Mitton, Wireless sensor networks, 30h eqTD, Université Lille 1, France

Master : Nathalie Mitton, RFID Middlewares, 16h eqTD, Institut Telecom and Université Lille 1, France

8.2.2. Juries

Nathalie Mitton was committee member of the following PhD thesis:

- Yacine Mezali, UPMC, Paris, France, March 2012
- Oscar Botero, Institut Telecom, France, May 2012
- Nazim Abdeddaim, Université de Grenoble, France, October 2012
- Gilles Fritz, ESISAR, INP, France, December 2012

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