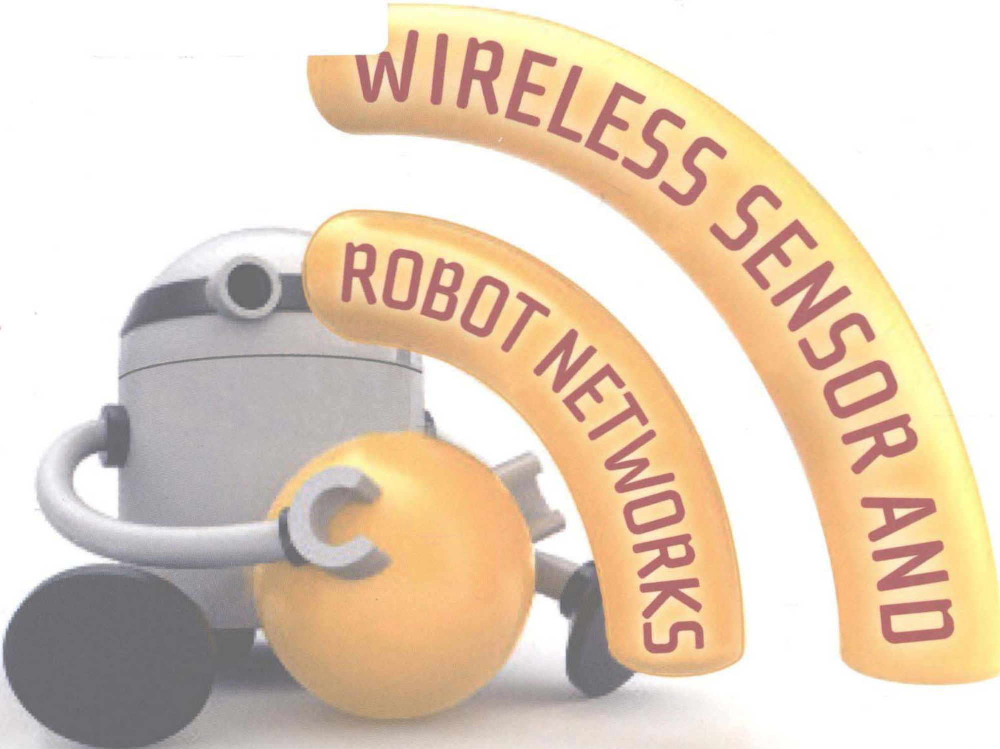

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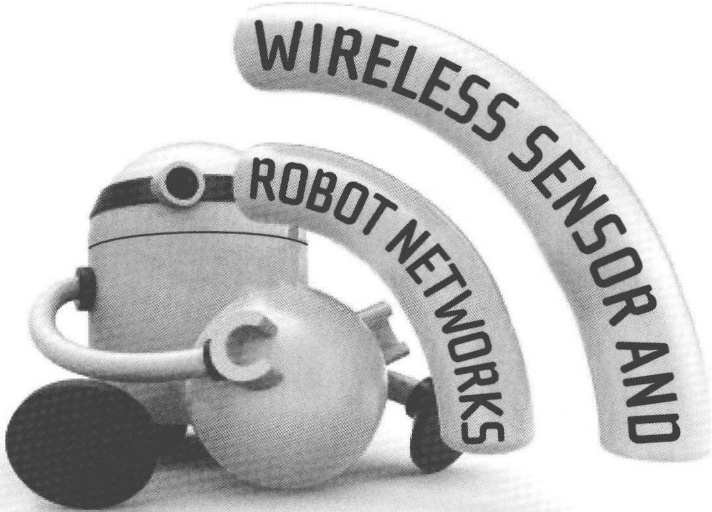

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From Topology Control to Communication Aspects

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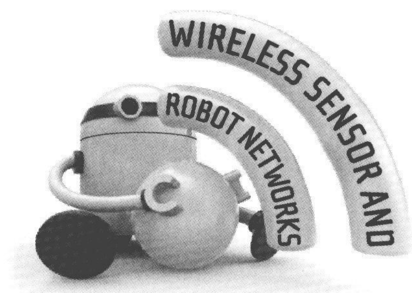

From Topology Control to Communication Aspects

Preface

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Wireless sensor networks have gained much attention these last years thanks to the great set of applications they allow and technological advances. One of these challenges is node mobility: sensors could be moved unexpectedly if deployed in an uncontrolled environment or hold by moving object/animals. Beyond all this, a new dimension arises when this mobility is controlled, i.e., if these sensors are embedded in robots. These robots cohabit with sensors and cooperate together to perform a given task collectively by still presenting hardware constraints: they still rely on batteries; they communicate through short radio links and have limited capacities.

The set of potential applications of wireless sensor and robot networks is very wide. We can divide the applications into three categories:

- fleet of wireless robots,
- wireless sensor network serviced by mobile wireless robots,
- wireless sensor and robot networks.

Fleet of wireless robots

In such applications, the network is composed of a fleet of wireless robots that need to cooperate to fulfill a given task. Robots constitute the nodes of the network. The tasks may greatly differ regarding the application but the most current envisaged ones today are operations of coverage, exploration and substitution networks.

Coverage

Coverage is one of the first fundamental goal of wireless sensor networks. Due to the large variety of sensors and applications, coverage is subject to a wide range of interpretations. For example, let's consider a wireless sensor network deployed in a forest for fire detection. One may ask how well the network can observe a given area and what the chances are that a fire starting in a specific location will be detected in a given time frame. Furthermore, coverage formulations can try to find weak points in a sensor field and suggest future deployment or reconfiguration schemes for improving the overall quality of service. The quality of coverage will thus depend on sensor relative location one to each other. For a given number of sensors, the best coverage will be achieved when the monitoring area of every sensor overlaps as less as possible. At the same time, sensors should be geographically close enough to ensure network connectivity.

The use of mobile robots instead of sensors allows the improvement of such a coverage. Indeed, in a plain wireless sensor network, sensors are generally deployed at random or based on a previous off-line computation that does not take the obstacles and ground constraints into account. Using mobile robots allows an adaptive and real time deployment that better fits the environment dynamics. Robots could self-deploy to cover and then monitor an area through their embedded sensors. They thus become the network nodes. An alternative is that they are sent to dynamically drop wireless sensors at specific positions. The choice between these options will be lead by the application. Do we need to send robots because the environment is highly dynamic and thus, to achieve a good coverage, they have to continuously re-position? Is the area to monitor unaccessible or dangerous to humans? In these latter cases, robots could be sent to deploy a wireless sensor network by dropping sensors on positions dynamically computed based on local features.

Coverage can concern several kinds of coverages: area coverage, barrier coverage or simply a point of interest coverage. Chapter 4 will detail the way these issues are technically addressed in the literature.

Exploration

These issues are detailed in Chapter 7. In such applications, a fleet of wireless cooperative robots is sent for exploration. Robots are usually used when sending human is not possible. This is for instance the case on other planets like the Curiosity robot on Mars planet or after/during a disaster.

Firemen send flying drones to supervise forest fire and better anticipate the fire propagation[1]. Today, all these exploration tasks are performed by a single robot that can be powerful and thus expensive. Next steps are to send a complete fleet instead in which robots are smaller, more manageable and self-cooperative. This will allow a quicker, more reliable and cheaper exploration. Also, using heterogeneous robots in such an application allows a step further than the plain exploration as the Swarmanoid[2] European project shows. It illustrates an exploration task in which a fleet of drones is in charge of locating a book. Once the book is localized, drones guide small ground robots to it. These small ground robots cooperate to carry a climbing robot which is able to retrieve the book in a high shelf. This is a simple application which gives an overview of the wide range of possibilities that a wireless mobile robot network can achieve.

Substitution networks

Chapter 5 gives a deep insight in substitution networks and the challenges they leverage. 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. When a failure in a primary network occurs, the fleet of wireless robots self-deploy to fulfill this network application with best QoS, *i.e.*, by position themselves not only to relay the message but to relay the messages with the best link quality. To do so, robots continuously measure the signal strength and move to the position that provides the best signal.

Wireless sensor network serviced by mobile wireless robots

The second category of applications of the mobile wireless sensor and robot networks in when a sensor network is serviced by robots. The idea here is that there exists an operational wireless sensor network that requires sporadic help/servicing from mobile robots. In this category, sensors and robots perform independently.

The first application to be highlighted is the node deployment. Indeed, if there is a need to monitor a specific area through the use of wireless sensors and that this area is unreachable by humans, a fleet of mobile robots can be sent instead to drop sensors on the area. Please refer to Chapter 4 for more details.

[1] http://www.bfmtv.com/planete/un-micro-drone-aide-les-pompiers-a-lutter-contre-les-incendies-220860.html

[2] http://www.swarmanoid.org

Then, once the network is deployed, mobile robots can bring new services. Some of them could be continuous like for instance providing recharge to nodes. The idea is that mobile robots travel around sensors to reload their energy, such allowing no network death. Such an issue is discussed in Chapter 6. The challenge here is to provide enough energy to every sensor node to ensure the whole network proper functioning. Several parameters have to been considered like the recharge time, the rate of energy to provide to sensors at once (the more energy, the longer the recharging time and the less sensors recharged).

Another examples of continuous services that could be provided by robots to sensors is localization and data gathering. In the former, the idea is that robots are aware of their real time position and travel close to every sensor in the network to share this information with it (See Chapter 9). Depending on the network dynamics, such a service could be done only once or coupled with the recharging model. In the latter, autonomous robots can travel over the area to be monitored to gather information from sensor nodes (See Chapter 2). These sensor nodes could be either fixed or mobile. In such a case, the purpose is to allow sensors to empty their memory and collect more monitoring information without lost. Robots have thus to be efficient enough to self-organize and path plan such that every sensor is visited regularly and on time.

One of the most interesting example of kind of services that could be brought by wireless robots to wireless sensors is on-demand ones. Such services mostly require real-time, which leverage a new challenge. In addition to gathering and reporting data from the environment, sensors may also report failures of neighboring sensors or lack of coverage in certain neighborhood. Such event information may be gathered by nearby mobile robots through multi-hop paths. Once an event has been detected, robots coordinate with each other to make a decision on the most appropriate way to perform the action. The main such applications are intruder tracking and fire detection and limitation. In the latter case, sensors trigger an alarm upon fire detection that is routed to robots. Robots cooperate and self-organize to reach the fire point and try to confine the fire by moving around it or if they can to deaden it while waiting for firemen. Issues related to such applications are addressed in Chapters 3 and 8.

In the intruder detection application, sensors detect an unusual intrusion and report it to robots and central entity. Robots speed up to the intrusion point, locate him/her based on data collected by the wireless sensors and track him/her. Note that such safety application is well on demand currently[3].

Wireless sensor and robot networks

This section gives a quick overview of what a wireless sensor and robot network can bring if all devices cooperate at the same level, taking heterogeneity features into account at each decision step and improving locally all performances. The basic applications could be the ones as described in Chapters 4 and 1 in which the robots are part of the wireless sensor network and act only to improve the performances of this latter like routing or coverage.

Wireless sensor and robot networks can be used for rescue operations. Imagine a disaster such as the Fukushima nuclear power plant that was damaged in 2011 by an earthquake and a tsunami. Human workers are better not to be sent to measure the damages because of radiations. Imagine that a fleet of robots is sent instead. Robots will cooperate to explore the area efficiently without interfering. They have to move in a cooperative and coordinated way to maintain communication links between them. Robots will evolve in an autonomous dynamic way in this hostile area taking decisions based on environmental information. These local data, either physical if directly sensed from their environment (such as a radiation rate) or from the other robots (for cooperation and communication purposes) will drive their actions and movements. They may drop static sensors along their paths for ensuring a communication link between several area points, or to ensure a continuous monitoring while they move ahead. These sensors will be later re-used for further explorations and accurate monitoring comparisons. How has the radiation level evolved since last exploration in this accurate place?

Similarly, wireless sensor and robot networks can be used for regular place monitoring and switch to an emergency situation by simply adapting to the events they sense and changes in environments. Let's illustrate such an application for museum safety and security. For this purpose, sensors are deployed in the museum to measure specific values such as temperature, humidity, carbon concentration, that impact the art major works preservation. Robots patrol to gather data from remote sensors or to change sensor batteries. In normal use, data collected by sensors and robots are normally sent to database for daily monitoring. If an anomaly is detected

[3] http://www.ocdelibrairie.org

by the sensors, it has to adapt. If an intrusion is detected after the museum closure, sensors triggers an alarm, robots will locate and possibly surround the intruder guided by sensor data and protect art major works located and identified thanks to sensors. If a fire or a flood is detected, sensors will guide robots that will shut up endangered areas, guide evacuated people to the exit via a safe way and guide rescue operations to victims. Sensors will also allow robots to identify high value art major works, isolate, evacuate or protect them. Then, robots will explore the damaged area dropping sensors to ensure a continuous monitoring.

Challenges

Many challenges arise due to the introduction of the controlled mobility. All these challenges many depend on the application requirements and expectations but globally, some of them are common to all of them. First, where and when a robot should move? How does it cooperate with the other robots of its fleet and coordinate to fulfill a given task without being in each other's way and with minimum energy? And one of the most important: the energy? How to preserve it as much as possible while ensuring a high quality service? When and who to reload and how much? Some of these challenges are discussed in the different chapters of this book and in particular in Chapter 10.

Energy is the most challenging issue. Indeed, before performing an action, a robot has to ensure that it will have enough energy to come back to its base station for reloading, except if the application tolerates to loose robots, which is rare because of the robots cost. The energy consumption is mostly due to robot communication and movement. Algorithms should thus consider in their design these consumption sources in order to minimize them by fitting with shorter path length and less communications. Then, it is strongly connected with hardware and battery discharge and reloading. How long does a robot need to recharge fully, half, etc. should be considered as well.

Then, task assignment is the second most challenging issue. It consists in selecting robots that will be sent together by assigning them specific distributed tasks such that the fleet at the whole will act in a coordinated and efficient way. Robots have to be selected carefully still with regards to energy consumption and environment. Should the algorithm select the closest robots? Or the ones with the higher level of energy? How many?

Some aspects of task assignment may require real-time or synchronization, short wireless communications, etc. Some solutions considering all these aspects jointly and reduce action redundancy should be investigated.

Globally, wireless robot and sensor networks need a unified framework in order to constitute a flat network with different services and heterogeneous components. Several cross-layer integration issues among the communication layers should be integrated in order to improve the global efficiency and performance of a wireless sensor and orbit network. There is still a need for real-time communication protocols for robot and sensor coordinations.

With the advance in hardware technology, all these applications are about to be deployed. There exist more and more wireless sensors and robots to be networked. We can also witness the apparition of new platforms for experimental testing like FIT[4] or Project Lab[5] that allow the improvement of software protocols allowing the autonomy of such networks.

There exist several actions around the world dealing with such issues. This is for instance the case of the following projects COGX[6], ROBOTCUB[7] or PACO-PLUS in which cognitive robotics approaches are used to make the robot self-understand and self-extend its abilities. SPARK2[8], IWARD[9], ROBOSWARM[10] and SENSOPAC[11] analyze cognitive collaborative models inspired by swarm behavior or for emerging cooperative robot behavior. COMPLACS aims at developing a unified toolkit for intelligent control in many different problem areas. This toolkit will incorporate many of the most successful approaches to a variety of important control problems within a single framework, including bandit problems, Markov Decision Processes (MDPs), Partially Observable MDPs (POMDPs), continuous stochastic control, and multi-agent systems.

At the ERA (European Research Area), several collaborative projects have been performed in robotics, 15 of them involve collaboration robot-robot. Among them, some deal with micro-robots (REPLICATOR and MICRON), underwater robots (MORPH, Co3 AUVs, CoCoRo and NOPTILUS) and thus focus on a specific environment, some are devoted to flying robots (sFLY and COMETS). Others investigate various re-

[4]fit-equipex.fr
[5]http://nootropicdesign.com/projectlab/2010/03/04/wireless-robotics-platform/
[6]http://cogx.eu/
[7]http://www.robotcub.org/
[8]http://www.spark2.diees.unict.it/
[9]http://www.iward.eu/cms/index.php
[10]http://roboswarm.eu/
[11]http://www.sensopac.org/

search/application problems for ground mobile robots. For instance ARCAS, MARTHA, IWARD, DustBot and ROBOSWARM projects deal with a fixed asset of sensors for transportation, area cleaning, construction or patrolling and URUS and GUARDIANS address the aspects of sensor placing and adaptation.

Brief outline of this book

This book is composed of 10 chapters discussing about the different issues brought by a wireless sensor and robot network. It does not pretend to be exhaustive but at least to draw the perspectives and the possibilities of such networks together with the challenges they raise and how previous researches have addressed them. The first chapters show how the addition of mobility in a wireless sensor network can improve the routing performances (See Chapter 1) or the data collection (See Chapter 2). Following chapters detail the issues appearing when several robots have to cooperate to service sensors (See Chapter 3), to ensure a coverage of specific points or areas (See Chapter 4) or to support a failing existing network (Chapter 5). Chapters 7 and 8 describe alternative solutions, showing how the swarm intelligence can be used for robot cooperation and coverage area. Chapter 9 introduces the different localization techniques that could be used in such networks. Finally, Chapter 10 concludes this book by discussing challenges and business applications.

Acknowledgements

The editors are grateful to all authors for their valuable contribution to this book. We hope the readers will find the information available in this book helpful and worth reading. Every feedback from readers will be welcome.

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