EUROPEAN SCHOOL OF ANTENNAS
Wireless Networks: From Energy Harvesting to Information Processing

CTTC, Castelldefels, Barcelona (Spain), 9-13 November, 2015

Summary:

Wireless Communication Networks are evolving towards heterogeneous and complex systems requiring large information processing capability, ubiquities and constant communication. Hence, traditional Wireless Sensor Networks (WSN) and Mobile Cellular Networks are evolving towards hybrid systems sharing common paradigms. In this course we focus on techniques that are to play an important role in the future of Wireless Networks. Although energy efficiency and power savings have always been present in the design of wireless communication systems, they have become one of the main drivers for research in WSN and Heterogeneous network devices.

In this course we will first provide an overview of energy harvesting techniques for autonomous devices, with the aim of providing an understanding of the HW technologies and RF aspects involved. This first block includes both theoretical and practical exercises: it will provide theoretical principles of wireless power transfer technologies, signal optimization and rectenna design for electromagnetic energy harvesting and wireless power transfer and practical exercises (rectenna design project).

The second part of the course deals with communication and information processing techniques that not only address energy efficiency but capacity and reliability issues. In this context, the course focuses on cooperative and distributed techniques with emphasis on coding schemes. Cooperative communications have proven to improve the capacity of wireless communications by allowing cooperation between devices at the physical layer level. Coding, present in all modern communication systems, provides reliability and implicitly energy savings by reducing transmission failures. In the same way reducing collisions in multiple access channels benefit energy efficiency. The objective of this course is to provide the fundamental tools to understand, analyse, and design cooperative communications systems and distributed information processing in general, and WSN in particular. The course will also provide a theoretical framework to understand the principles of suitable communication strategies and other relevant aspects of the communication system design in the presence of power-limited/energy-harvesting devices.

The lectures will cover the following areas:

FIRST BLOCK: RF ASPECTS

1. **Energy harvesting and wireless power transfer for autonomous devices (sensors)**: Review of energy harvesting technologies. Challenges and recent developments demonstrating wireless sensors circuits operating without a battery are presented. Examples include solar energy assisted RFID tags, solar powered active antennas, passive antenna based sensors, wireless powering of consumer electronics. The principles of wireless power transfer technologies from near-field to far-field are presented.

2. **Signal optimization and rectenna design for electromagnetic energy harvesting and wireless power transfer.** Rectenna design methodologies, state-of-the-art, challenges and novel research directions are presented. Wideband and multi-band rectenna designs are presented. Investigation of different signal waveforms such as multi-tone signals, noise and chaotic signals and their effect on the wireless power transfer efficiency is discussed. Simultaneous wireless power and information transfer will be considered with emphasis on backscatter radio design and combined ultra wideband (UWB) radio and UHF RFID.

SECOND BLOCK: INFORMATION PROCESSING ASPECTS

1. **Background material**: Basics on communication theory, multiuser information theory and coding.
2. **Distributed information processing and Coding**: Advances on cooperation techniques and distributed information processing will be presented. Special emphasis will be given to coded systems analysing techniques such as physical layer network coding for wireless transmissions. Design of energy management policies for EH communication systems, description of analytical models.

PRACTICAL EXERCISES:

1. **Rectenna design student design project contest**. As part of the assignment, students are required to develop a complete rectenna design including an antenna and rectifier circuit, based on a defined set of specifications. The work will be carried out in small groups.

	Lectures	Laboratory, computer exercises and personal work	Total	Credits	Assessment typology
STRUCTURE OF THE COURSE	16 h	12 h	28 h	2 ECT	Attendance and assignment

Registration and additional information at http://www.antennasvce.org/Community/Education/Courses and http://esoa2015.cttc.cat

COURSE SCHEDULE

	Monday: Introduction	
Time	Topic	Lecturer
9:00-10:00	**Welcome and Course introduction**	*Monica Navarro, CTTC, Spain*
10:00-11:00	**Basics of Communication theory**	*Monica Navarro, CTTC, Spain*
11:00-11:30	Coffee Break	
11:30-13:00	**Energy harvesting and wireless power transfer for autonomous sensors and RFIDs**	*Apostolos Georgiadis, CTTC, Spain*
13:00-14:30	Lunch	
14:30-17:30	**Work assignment: Rectenna design student design project**	*Apostolos Georgiadis, CTTC, Spain*

	Tuesday: Energy Harvesting and Wireless Power Transfer Technology I	
Time	Topic	Lecturer
9:00-10:00	**UWB -UHF circuit and system solutions for simultaneous wireless powering, tracking and sensing at ultra-low power.**	*Alessandra Costanzo, University of Bologna, Italy*
10:00-11:00	**Wireless Power Transfer: From Far Field to Near Field**	*Jenshan Lin, University of Florida, US*
11:00-11:30	Coffee Break	
11:30-13:00	**Design Method of High Efficiency Rectenna for Microwave/Millimeter Wave Power Transfer and Energy Harvesting**	*Naoki Shinohara, Kyoto University, Japan*
13:00-14:30	Lunch	
14:30-16:30	**Work assignment: Rectenna design student design project**	*Apostolos Georgiadis, CTTC, Spain*
17:30-18:30	**Visit to Barcelona Supercomputing centre**	

	Wednesday: Energy harvesting and Wireless Power Transfer Technology II	
Time	Topic	Lecturer
9:00-10:00	**Optimal signal selection and rectenna design for electromagnetic energy harvesting and wireless power transfer**	*Apostolos Georgiadis, CTTC, Spain*
10:00-11:00	**Passive Radio Communications combining backscatter with WPT**	*Nuno Borges Carvalho, Institute of Telecom., University of Aveiro, Portugal*
11:00-11:30	Coffee Break	
11:30-13:00	**How to Write a Paper for IEEE MTT-S Journals and Navigate the Review Process**	*George Ponchak, NASA, US*
13:00-14:30	Lunch	
14:30-17:30	**Work assignment: Rectenna design student design project**	*Apostolos Georgiadis, CTTC, Spain*

	Thursday: Information processing I	
Time	Topic	Lecturer
9:00-11:00	**Energy Harvesting Communication Network Design**	*Deniz Gunduz, Imperial College London, UK*
11:00-11:30	Coffee Break	
11:30-13:00	**Cooperation and Coding**	*Monica Navarro, CTTC, Spain*
13:00-14:30	Lunch	
14:30-17:30	**Work assignment: Rectenna design student design project and evaluation**	*Apostolos Georgiadis, CTTC, Spain*
21:00	**Social dinner**	

	Friday: Information processing II	
Time	Topic	Lecturer
9:00-11:00	**From Network Coding to Uncoordinated Multiple Access**	*Stephan Pfletschinger, DLR, Germany*
11:00-11:30	Coffee Break	
11:30-13:30	**Final assessment, student questionnaire**	
13:30-14:30	Lunch	

LECTURES ABSTRACTS

Wireless power transfer: from far field to near field
Prof. Jenshan Lin, University of Florida, Gainesville, FL, USA

The interest in wireless power transfer or wireless charging has been growing rapidly in recent years. Many researchers and engineers that worked on different fields are now focusing on this topic. In this talk, I will present an overview of wireless power technologies including far-field microwave power transmission, wireless energy harvesting, and near-field magnetic coupling. The advantages and disadvantages of different technologies as well as their applications will be discussed. I will give my perspective on why the near-field wireless power transfer is a better choice for charging consumer electronic devices and where/when the far-field microwave power transmission will be needed. The concept of loosely coupled near-field wireless charging to allow flexible placement and the design challenges will be discussed. A few examples demonstrated by my group including a 10-W system for wireless charging mobile devices, a 300-W system, and a system for wirelessly charging a laptop computer with load-detection capability, will be described.

Design method of high efficiency rectenna for microwave/millimeter wave power transfer and energy harvesting
Prof. Naoki Shinohara, Research Institute for Sustainable Humanosphere, Kyoto University, Japan

A rectenna, rectifying antenna, is one of key technologies for a wireless power transfer via radio waves or energy harvesting from radio waves. The rectifying circuit of the rectenna is a diode circuit to rectify the radio frequency (RF) to direct current (DC) with high efficiency. Higher frequency like a microwave and a millimeter waves is required to increase beam efficiency from a transmitting antenna to a receiving antenna in the wireless power transfer system. But the RF-DC conversion efficiency of the rectenna decreases with higher frequency. It is mainly depends on the characteristics of the diode. For the energy harvesting, received radio wave power is very weak and the RF-DC conversion efficinecy also decreases at the weak power density. It is also because of the diodes. So we need a method of rectifying circuit design for high efficiency rectenna. In my talk, various developed rectenna are introduced. Based on the past rectenna designs, a design method of high efficiency rectennas for microwave/millimeter wave power transfer is explained.

UWB -UHF circuit and system solutions for simultaneous wireless powering, tracking and sensing at ultra-low power.
Prof. Alessandra Costanzo, University of Bologna, Italy

This lecture will describe the design steps and issues of antenna systems, combining UHF and UWB technologies for next generation RFID-enabled sensor systems. Integrated techniques using electromagnetic simulation and nonlinear CAD will be discussed to provide compact solutions without losing efficiency of the whole system. In the last years impulse-radio ultra-wideband (IR-UWB) technologies have demonstrated to be a promising solution to indoor localization problems, with sub-meter precision, thanks to their interference robustness characteristics. Furthermore one of the advantages in adopting UWB communication is the ultra-low power consumption, which makes it possible to deploy battery-less RFID sensors by exploiting radiofrequency (RF) energy harvesting. An integrated solution, to keep the same radiating element for both communication and energy harvesting, will be discussed to take the advantage in collecting RF energy from the ambient by exploiting the UHF band, which is roughly one order of magnitude higher in terms of rectified power with respect to the UWB band. Hybrid UWB-UHF RFID systems will be discussed together with several solutions of co-localization of UWB and UHF antennas. An entire link set-up demonstrating the operation feasibility will be presented at the end.

How to write a paper for IEEE MTT-S journals and navigate the review process
Dr. George E. Ponchak, NASA Glenn Research Center, US

The careers of many people depend on their success in writing and getting their papers published. More important, the scientific process requires that scientific findings be published so that other researchers may build on your ideas or refute your findings. If authors are not able to publish their papers, then their careers are hurt and scientific progress slows and stops. Therefore, it is critical that researchers and engineers understand the process of writing and getting published their papers in reputable and cited journals and scientific conferences. However, often, authors' papers are rejected because they did not understand what reviewers, Associate Editors, and Editors are looking for in a paper, even if the technical results are good. This presentation will cover the steps that an author should take to increase the acceptance rate of their papers in journals and conference. It will cover the reasons most papers are rejected and how an author should organize their paper to avoid those reasons. Lastly, it will present what steps you should take if your paper is rejected to get it published in the same journal or in a different journal.

Passive radio communications combining backscatter with wireless power transfer (WPT)
Prof. Nuno B. Carvalho, Institute of Telecommunications, University of Aveiro, Portugal

This talk will address some of the backscatter radio design strategies for development of radios that do not use DC power for communications. In this talk these radios will be combined with WPT to increase radio coverage and battery substitution.

Energy harvesting and wireless power transfer for autonomous sensors and RFIDs
Dr. Apostolos Georgiadis, Centre Tecnologic de Telecomunicacions de Catalunya, Spain

Energy harvesting technologies are receiving significant interest from industry and academia as they provide a foundation, an enabling technology towards the realization of 'zero-power' wireless sensors and implementing the Internet-of-Things (IoT) and machine-to-machine (M2M) communication. The state-of-the-art in commonly used energy harvesting technologies such as solar, piezoelectric, thermal and electromagnetic is presented. Figures of merit are provided and emphasis is placed on design challenges and novel technologies and materials, such as paper, textiles, and inkjet printing fabrication. Hybrid–multiple technology harvesters are discussed and the development of low profile and conformal solar antennas and solar–electromagnetic harvesters is presented. Interest in electromagnetic energy harvesting is further attributed to the capability for powering of wireless devices by intentional radiation known as wireless power transmission. Circuit and system examples of autonomous system operation are demonstrated such as wirelessly powered sensors, beacon signal generators, and energy harvesting applied to RFID systems.

Optimal signal selection and rectenna design for electromagnetic energy harvesting and wireless power transfer

Dr. Apostolos Georgiadis, Centre Tecnologic de Telecomunicacions de Catalunya, Spain

System and circuit concepts leading to improved rectenna efficiency are discussed. The use of multi-sine, white noise and chaotic signals for optimum rectifier performance is presented. Furthermore, design challenges of wideband versus multi-band rectennas and the efficient combination of multiple energy harvesting module outputs are discussed. Finally, the use of resistance compression networks reducing the effect of load impedance and input power variation to the rectenna RF-DC conversion efficiency is demonstrated.

Basic Concepts of Communication
Dr. Monica Navarro, Centre Tecnologic de Telecomunicacions de Catalunya, Spain

This lecture will provide an overview of the basics of communication and information theory. We will start the lecture with a review of the channel capacity for a variety of single-user channels and discuss its meaning for practical communication systems. In the second part of the talk, we will extend the discussion to multiple users and show on the one hand the limits of multi-user communications given by information theory and on the other hand explain the most relevant practical multiple-access schemes.

Energy Harvesting Communication Network Design
Dr. Deniz Gunduz, Imperial College, London, UK

Communication devices powered by energy harvesting (EH) are becoming a reality, replacing their traditional, battery-operated counterparts, especially when the sheer number of nodes or inaccessibility render battery replacement difficult and cost-prohibitive. Their deployment spans the whole gamut of autonomous networked systems: from machine-to-machine and sensor networks, to smart buildings and grid asset monitoring. In contrast to battery-operated devices, where minimizing energy consumption is crucial to prolong lifetime, in EH-powered devices, the objective is the intelligent management of the harvested energy to ensure long-term, uninterrupted operation.

This lecture will provide an overview of recent developments in the design of energy management policies for EH communication systems. We focus on analytical models that capture the main challenges related to their design: the intermittent nature of harvested energy, the limited capacity and energy leakage in energy storage devices, and the constraints on device size and complexity. We will examine in detail point-to-point as well as multi-user networks and explore the implications of EH on their performance.

Cooperation and Coding
Dr. Monica Navarro, Centre Tecnologic de Telecomunicacions de Catalunya, Spain

This lecture will introduce the benefits of cooperation in wireless networks providing an overview of most relevant cooperative schemes using the relay channel as the reference. It will also introduce aspects of coding by reviewing the principles of coded cooperation. Finally, we will examine the application of coding principles at upper layers by providing an overview of fountain codes and network coding.

From Network Coding to Uncoordinated Multiple Access
Dr. Stephan Pfletschinger, German Aerospace Center (DLR), Germany

This lecture will show in some detail the principles of wireless (physical-layer) network coding. We will use the two-way relay channel as a canonical example and develop in some detail the various approaches of modulation and coding for this channel, including constellation design, lattice coding, successive interference cancellation and joint decoding. These principles will then be applied to uncoordinated multiple access schemes, which play an important role in machine-type communication.