Sujet de thèse EEA:

PARTIE I

Etablissement d'inscription : INSA de Lyon

Ecole doctorale : ED 160 EEA de Lyon

Intitulé du doctorat : 2. Electronique, Micro et Nano-électronique, Optique et Laser

Sujet de thèse : Etude et développement des architectures de récepteurs radio autonomes en énergie et de leurs mécanismes d'éveil et de récupération d'énergie /
Study and development of architectures of radio receivers autonomous in energy and their mechanisms of wake-up and energy harvesting.

Unité de recherche: CITI

Directeur/trice de thèse : Guillaume Villemaud

Co-directeur/trice de thèse (le cas échéant):

Co-directeur/trice de thèse en enntreprise (le cas échéant) :

PARTIE II

Domaine et contexte scientifiques : Nowadays, we are living the emergence of the Internet of Things (IoT) in all human activities like transportation, home automation, "smart office/factory", health, etc. and we can imagine that in a few years, every object of our everyday life will exchange some information using a radio link. Since the "birth" of the IoT between 2008 and 2009, when the numbed of connected objects surpassed the world's population, Gartner agency forecast is of 20.8 billion connected objects from 2020 and, for the same horizon, CISCO forecasts 50 billion [1].

In most of the scenarios, the communicating objects have a low duty-cycle transmission rate, limited energy resources (because they are battery- or self- powered) and may, in certain cases, be deployed in unreachable locations. For example, imagine that there are hundreds of pressure sensors embedded into asphalt in order to monitor the traffic conditions. It would be quite impossible to replace the batteries of all the sensors without major financial costs. In the medical domain, the battery replacement of such kind of objects involves some surgery with all the implications that this may bring. Moreover, the amount of wasted energy by such connected objects in standby mode is spectacular. Indeed, in [2] it is predicted a 20 % annual increase of the worldwide IoT edge devices energy consumption in standby mode. Consequently, in 2025 this residual consumption would be equal to Portugal's entire annual electricity consumption of the year 2012!

Moreover, it has been estimated by the IEEE 802.11ba standards task group that half of the internet connected sensors and devices will run on batteries by 2020. This is why the IEEE Standard Association is working on a new standard for low power receivers (wake-up radio). The IEEE Wake-Up Radio technology aims is to significantly increase the battery life up to two years and could allow to some devices to remain accessible all the time without draining their batteries [3].

These are the reasons why the energy consumption optimization is one of the crucial aspects that should be addressed. At every level, strategies are proposed to optimize the energy consumption of the connected objects. At the radio front-end level, the research is focusing on the increase of the power

amplifiers' energy efficiency, the most energy greedy part of a radio transceiver. Energy friendly hardware and software architectures like computational RFID are proposed in order to integrate energy harvesting together with communication for better energy efficiency. At even higher levels, media access protocols (MAC) are optimizing the overall energy consumption of the network. Together with this reduced energy consumption of the connected objects, we assist to an increase of the efficiency of the energy harvesting strategies. Depending on the application, different kinds of energies can be harvested with relatively high efficiency: mechanical, radiofrequency (RF) [4], solar or thermal and the use of this energy to power supply the connected objects seems to be a reliable solution. Moreover, recent research in this field is focusing on generating new waveforms in order to adapt the signal carrying the energy to the propagation channel [5].

Mots-clefs: wireless communications**,** RF architecture, Wake-Up radio, Energy Harvesting, Wireless Power Transfer.

Objectifs de la thèse:

The general objective of this thesis is to propose alternatives to reduce the energy footprint of the connected objects with a focus on the radio front-end part. One of the common ways to reduce the energy consumption and implicitly increase their autonomy is to propose energy friendly MAC mechanisms consisting in turning off periodically the radio transceiver. This seems to be a good solution for the low duty cycle transmissions but it can lead to an increase of the network delay and to a less reliable communication, which contradicts the requirements of certain critical applications. Another way to reduce the energy consumption of the connected objects is to use an auxiliary, ultra-low energy consumption receiver, called wake-up radio (WuRx). The role of a wake-up radio is to "listen" to the communication channel and to switch on the main transceiver only when a communication demand appears. Recent researches were able to decrease the energy consumption of the wake-up radios to levels below a microwatt [6], in such a way that it becomes feasible to keep them turned on permanently during the standby period.

The current technologies used for the wake-up receivers varies from simple passive energy detector to more complex homodyne receivers. Generally, the identifier of the node to wake up is sent over the air by using the OOK (On-Off Keying) modulation because of the simplicity of the receiver that can be a passive envelope detector. More recent approaches, developed at CITI laboratory, proposed the use of multi carrier signals like OFDM (Orthogonal Frequency-Division Multiplexing) or even FBMC (Filter Bank Multicarrier) in order to send the identifiers [7,8], thereby eliminating the need of a microcontroller (usually employed for decoding the identifier) thus making a step forward toward a passive wake-up radio receiver.

The main scientific challenge of the thesis is to propose an autonomous wake-up radio architecture, i.e. an ultra-low power receiver supplied by the RF harvested or transferred energy and independent from the connected object's main power supply.

More thoroughly, the aim of this subject is to explore new solutions based on autonomous wake-up radio receivers taking into account limitations as size, technologies, operating conditions, etc., in order to provide one (or several) operational prototype(s). The proposed solutions will not exclusively be evaluated and optimized in terms of energy consumption, but also will take into account the communication performance such as the sensitivity and the robustness in terms of false wake-ups. The starting point of this study is the quasi-passive wake up radio receiver proposed and experimentally validated at CITI laboratory [6]. The architecture proposed herein allows making the connected object independent from the main battery supply during the standby mode.

Verrous scientifiques: The main bottleneck of Wake-Up radio systems and Wireless Power Transfer is the maximum range of the system and the overall efficiency. A global optimization in terms of energy efficiency of this kind of system taking into account all parts (source(s), radio channel and rectifier) will be also an important breakthrough.

Contributions originales attendues:

The architecture proposed in [7] is based on rectifier circuits, similar to RF energy harvesting circuits. This gives the opportunity of using the same structure to wake-up the main radio front-end and to harvest electromagnetic energy in order to power supply the active parts of the wake-up radio.

This approach raises some scientific and technological challenges. The definition of different usage scenarios will allow establishing if the energy balance is positive or not. For the scenarios where the opportunistic harvested energy is not sufficient to power supply the active parts of the wake-up radio, energy containing packets may be transmitted. It is shown in the literature [9] that the energy transmission with signals having high PAPR (peak to average power ratio) is more efficient than in the case of using continuous waves. This is why, one of the scientific challenges of the thesis is the study of energy efficiency when using chaotic or FBMC (filter bank multipath carrier) signals to build energy supply waveforms. This work was partially started and the benefit of using such waveforms with WuRx was demonstrated in [8].

A wake-up radio have to address the compromise between the communication range and energy consumption. The ambition of the thesis is to break the state of the art limits by combining the knowledge of radiofrequency circuits and systems models, propagation channel models, and signal processing, thereby proposing an autonomous wake-up radio with increased communication range and robustness. Indeed, the wake-up radio's operating range is often very short since its sensitivity is discarded to the detriment of the energy consumption and this may be a drawback for different use-cases. The use of beamforming as a way to overcome the propagation channel effect (e.g. in terms of coherence bandwidth) and so to increase the received power level is another scientific challenge addressed in the thesis. This solution is intensively studied for the 5G where large-scale antenna arrays are intended to be used in order to increase the efficiency of the wireless power transfer [5]. Another solution is to share the LNA (low noise amplifier) with the main receiver that may be a good compromise for the scenarios with high levels of harvested energy.

Programme de recherche et démarche scientifique proposée:

This thesis will be globally divided in 3 tasks, each task corresponding roughly to one year of study.

Task1 (Wake-up radio scenario usage) is dedicated to the definition of the typical usage scenarios for the wake-up radio. Here, for each scenario, the communication range, the propagation conditions and the addressing needs will be identified. During this task, the feasibility of autonomous wake-up radio will be studied and, for each usage scenario, the complete energy budget will be evaluated.

Task2 (Energy harvesting waveforms and wake-up radio architecture definition) is dedicated to the study of energy harvesting waveforms. Here, by using models of RF power detectors, the harvested energy of different high PAPR waveforms will be compared. Moreover, the feasibility of increasing the WuRx range by using beamforming (or other multi-antenna) techniques will also be addressed. Another aspect addressed here is the definition of the wake-up radio architecture (s) by taking into account all usage scenarios and energy budgets.

Task3 (Wake-up radio prototype manufacturing and the measurement campaigns) will allow us to validate the proposed approaches through the characterization of functional prototypes. The gains in terms of energy consumption and latency introduced by the innovative, battery free WuRx will be measured by using two of the experimental facilities developed at CITI laboratory: http://www.citi-lab.fr/portfolio/radio-platform/ and CorteXlab: http://www.cortexlab.fr/.

Encadrement scientifique: Guillaume Villemaud (HDR, 50%), Florin Hutu (50%).
Guillaume Villemaud will bring his background on RF architectures, and Florin Hutu will co-supervise with an increased focus on theoretical aspects, RF electronics and experimentation. Both have a strong experience on signal processing and combination of analog and digital systems for low-power communications. The thesis will be 100% at CITI Lab.

Financement de la thèse: Ecole doctorale EEA

Profil du candidat recherché: Master of Sciences or Engineering degree in Telecommunications or Electrical Engineering with a strong background in radiocommunications, RF architectures and signal processing.

Compétences qui seront développées au cours du doctorat: Global knowledge of Front-end RF architectures, Wake-Up radios, Energy harvesting and Wireless Power Transfer. A complete skill of managing a research project from theoretical study, to simulation setup and experimental validation will also be of great value.

Perspectives professionnelles après le doctorat : both profiles of career in academic structures or R&D division in industry could be targeted after this thesis.

Références bibliographiques sur le sujet de thèse :

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[7] F. Hutu et al.; *A new wake-up radio architecture for wireless sensor networks*; EURASIP Journal on Wireless Communications and Networking, pp. 1 – 10, 2014; https://link.springer.com/content/pdf/10.1186%2F1687-1499-2014-177.pdf.

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[9] A. Boaventura et al.; *Boosting the efficiency: Unconventional Waveform Design for Efficient Wireless Power Transfer*; IEEE Microwave magazine, vol 16, no 3; pp. 87 – 96, 2015; http://www.av.it.pt/nbcarvalho/wp-content/uploads/2015/10/boosting.pdf.

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