Proposed Internships in IRCICA, Villeneuve d'ASCQ, FRANCE, in 2018.

Keywords - IoT / Sensor networks / Information Theory /Digital communication / Signal Processing Network / MAC / Hard-Soft / Localization / Sound

We are looking for high level students for several internships that have to take place in 2018. We are rather flexible in this time frame.

- The proposal addresses different levels of study. Most of them concern **M2** (eventually **M1**) but Topics 4-5 could eventually interest highly motivated **L3** students.

- If all contexts are related to IoT, proposed topics concerns many different topics:
    - information theory, signal processing and digital communication (topics 1 & 2)
    - Signal processing: sound (topic 4) and localization (topic 6)
    - Computer science and network architecture (topic 3)
    - Hard/soft realization of IoT nodes – electronic, software (topic 4 & 5)
    - MAC layer design (topic 7)

- **The selected applicants will receive a grant of about 540€ per month during** their internship.

Contacts: Send your application to laurent.clavier@imt-lille-douai.fr, mentioning the selected topic(s). He will distribute to the concerned people. If you do not receive an ACK in the two following days, check if the message was well received by asking. The application must contain a CV and a short motivation letter. Any supplementary information can be welcome. Do not hesitate to contact him for any further information.

Proposals

IoT & neuro-inspired Communications

Context: *ad hoc* sensor networks, for example for smart city or smart building applications or for the Internet of Things (IoT), create a growing need for data transmission, undergoing a still unsolved strong constraint on their energy consumption. To address the problem, more and more researches are turning to neuro-sciences: indeed, our brain is a very good example of a complex system, where many excitable cells (neurons) communicate with each other by transmission of elementary bioelectric signals (spike - or action potential), in order to ensure complex macroscopic functions, such as the classification or detection, with a minimal energy cost.

Our goal is to achieve neuromorphic circuits with ultra-low consumption in order to increase significantly the lifetime of the nodes and networks while ensuring a reliable communication. In particular, we wish in a first step to develop wake-up radio circuits: they are very critical because the MAC (to access the resource) layers consume a lot of energy in establishing communications, even before conveying any useful information. In this context two subjects of internships are available.

Topic 1: A mathematical model of neuron to spike to a model practice

Supervisors: Anne SAVARD, Laurent CLAVIER
Themes: information theory, signal processing, electronic
Level: M2, potentially M1
Duration: 4 to 6 months

Objectives:

- To take into accounts the physical constraints and intrinsic variability of used electronics
- To estimate the distributions of inter-spike durations for a LIF neuron
- To take into account the memory effect

A first study allowed to derive the performance of a digital communication based on Integrate-and-Fire (IF) neurons. This model, although very simple, is unfortunately not feasible in practice. Indeed, there are always losses, transforming the model IF in the Leaky IF (LIF), which, although too simple to represent biological neurons, is already a better approximation. One of the goals is to determine the theoretical performance of a digital communication using this LIF neuron. On another hand, even if the electric circuit is the same for all the neurons in a circuit, there is an intrinsic variability in electronics so that the neurons have different characteristics. When it comes to use several neurons in parallel, one must therefore take into account and use this plasticity. This study will be compared with simulations and on-chip measurements developed within the IRCICA.

The second step, in order to propose a neuron model closer to a true biological neuron, it is necessary to introduce the effects of memory in our mathematical models. However, taking into account this memory, from the point of view of information theory, is not trivial. The work in [1] showed that, in some situations, memory allows to increase the capacity of a channel and [2] focused on the rate of information for a binary channel in memory. This work could be a good starting point for a study of the performance of more realistic neurons from the biological point of view.

[1] J. Wolfowitz, "Memory capacity increases", *Information and Control*, vol. 11, no.. 4, pp. 423-428, October 1967.
[2] D. Arnold and H.-A. Loeliger, "We the information rate of binary-input channels with memory," in *ICC2001*, Helsinki, Finland, pp. 2692-2695, IEEE, 2001.

Topic 2: Multi-layer spiking neural network

Supervisors: Anne SAVARD, Laurent CLAVIER
Themes: signal processing, learning
Level: M2, potentially M1
Duration: 4 to 6 months

Objectives:

- Study of the performance of a group of LIF neurons for the recognition of a specific sequence
- Extension to the case when the input signals are a series of Spikes and neurons of the FIS

In a context of wake-up radio, the neuron must be able to recognize a sequence of bits, in other words its ID, in order to wake up the processor only in case of data communication to this node. We can then consider two types of neural networks: either of a single layer or multi-layer networks.

Thus, if a single layer of neurons is necessary, the input to this layer is a noisy binary signal. A first study on a theoretical model has already helped to determine the performance of such a network. However, if several layers of neurons are necessary, the entrance of the following layers will consist of spikes. A theoretical study of neurons with this kind of input is therefore necessary in order to characterize a multilayer neural network.

Initially, this study will be carried out considering a model Integrate-and-Fire (IF), but may be extended to a leaky IF model.

IoT nodes and system design

Context: While Internet of Things (IoT) is a hot topic addressed by the research community and subject to some commercial solutions, tremendous research challenges remain to be addressed. However research and industrial efforts are still fragmented, giving rise to as many *ad hoc* solutions as case studies you can imagine. Heterogeneity, large-scale deployment, privacy and security issues, long-term energy consumption but also data processing and impact on users give rise to numerous studies, but no real comparison or fully cross-layer designs has been achieved so far.

These projects aim at deploying an open cyber-physical infrastructure to foster interdisciplinary research topics related to IoT. It targets the deployment of an *in situ* pilot platform to

1) monitor different types of environmental data with autonomous nodes over the Lille University campus (in IRCICA and in LILLIAD, a learning center of Lille University);
2) Make the environmental data available online—through OpenData standards—to all interested parties (researchers in several fields, general public, local authorities), according to their needs and requirements; and
3) Exploit the environmental data for scientific studies, such as user comfort in a library, meter-scale air pollution, pollutant source apportionment, urban planning and transportation, environmental health, public involvement...

Topic 3: Connecting the sensing nodes to the cloud infrastructure

Supervisors: Romain Rouvoy (CRIStAL), Rédha Kassi, Laurent Clavier (IRCICA).
Themes: Computer science, Network design
Level: M1 or M2
Duration: 4 to 6 months

Many efforts have already been deployed to get the platform ready. However there are still important challenges that remain, related to the link between the gateways and the remote database. This step is crucial and solving it in a proper way is required in order to deploy more flexible networks (in the data sources and in the architecture to adapt to different types of environment – indoor, outdoor, dense networks or isolated nodes – while ensuring the long nodes' life...).The objective is to **develop the final software version to connect all the sensing nodes to the cloud infrastructure and to publish an open database** (while ensuring security and privacy) in order to deliver a simplified access to data to users. The work plan is defined as follows:

1) Discover and understand the full network architecture; (1 month.)
2) Develop the links gateways-APISENSER through Ethernet links and/or WIFI; (2 months.)
3) Develop direct links between nodes and APISENSER through Low Power Wide Area Networks like Lora and/or Sigfox; (2 months.)
4) Test and finalize the software solution (1 month.)

Topic 4: Noise Pollution

Supervisors: Nicolas Côté, Alexis Vlandas (WAVELY), Rédha Kassi, Laurent Clavier (IRCICA).
Theme Sound, signal processing, hardware implementation
Duration: 4 to 6 months
Level: L3, M1 or M2

The goal of this project is to propose an integrated sound quality sensor for the future Lilliad demonstrator. These acoustic sensors, consisting of a MEMS microphone, a processing unit and a dedicated power management block, enable continuous measurement of acoustic and digital indicators, which intelligently combine to estimate intelligibility of the environment, the occupation of the premises, even counting the number of people in a room, or the discomfort perceived by the users. The challenge is then to make our sensors fully autonomous (in energy). For this, we want to study the impact of the type of processing card (programmable logic circuit, optimized microprocessor for the sound signal processing) on the energy consumption. Several parameters will be taken into account in this study, including energy consumption, the quality of treatment and the cost of hardware solutions. As part of this task, we propose to deploy about fifteen acoustic treatment nodes, ideally linked to the communication platforms already present on the demonstrator.

Topic 5: Lora and localization – Node design and network architecture

Supervisors: CSAM (Laurent Clavier, Alexandre Boé), 2XS (Thomas Vantroys), LITUUS (Viktor Toldov, Román Igual).
Theme: LoRa radio, hard/soft node design
Duration: 4 to 6 months.
Level L3, M1 or M2

This task aims to develop an indoor or outdoor geolocalization system based on LoRa technology integrated and interfaceable to nodes deployed in Lilliad but also to the LITUUS system of collars connected to the farm. We hope to have an accuracy of less than 5 meters with energy autonomous anchors. The study of the signal parameters used as well as the number and position of the beacons on the measurement perimeter will make it possible to evaluate the performance of the localization and determine the optimal configuration.

The system will initially be simulated on a numerical calculation software and then realized within the IRCICA Telecom platform. The ultimate goal will be to test this life-size system in the Lilliad center but also on a cattle farm partner of LITUUS.
Planning

- Definition of the infrastructure architecture - the communication node must not change ;
- Set-up experimentation and measurements, development of the embedded software. Anchors synchronization is delicate.
- Real experimentation in IRCICA, Lilliad and a farm.

Topic 6: Lora and localization – Localization algorithm

Theme Localization, signal processing, LoRa
Partners : CSAM (Laurent Clavier, Alexandre Boé), 2XS (Thomas Vantroys), LITUUS (Viktor Toldov, Román Igual).
Duration: 4 to 6 months.
Level: M1 or M2

The goal of this topic is similar to Topic 5: developing an indoor or outdoor geolocalization system based on LoRa technology. This second trainee perform a mathematical study and use the system developed by the first trainee to geolocate objects with the desired accuracy. In the first phase, the system will be simulated on a numerical calculation software. The ultimate goal will be to test this life-size system in the Lilliad center but also on a cattle farm partner of LITUUS.

Planning

- Definition of the scenarios.
- State of the art on localization techniques.
- Development of localization algorithms. Based on the work in the paper by I. Nevat *et al*., “Location of things : Geospatial tagging for iot using time-of-arrival,” in *IEEE Transactions on Signal and Information Processing over Networks*, vol. 2, no. 2, pp. 174–185, June 2016.
- Real experimentation in IRCICA, Lilliad and a farm.

Topic 7: Dual Mode Low power Low latency PHY/MAC transmission design for LPWAN.

Supervisors: Nathalie Mitton (INRIA), Laurent Clavier, Anne Savard (IRCICA).
Theme: IoT, MAC and PHY layers
Duration: 4 to 6 months.
Level M2.

Efficient access to the network is a widely studied topic. However, the topic is very differently addressed in the different encountered communities:

- in information theory, the research mainly focuses on efficient ways to model the whole networks, taking into account multi-users, imperfections in the channel state information, short packets and limited latency and searching a good tool to handle the complex optimization problems ;
- at the PHY Layer, non-orthogonal multiple access, massive MIMO or distributed solutions, transmission at higher frequencies are the main challenges. In IoT, a challenging and important issue is probably to design very efficient, possibly distributed, gateways. It will allow simple transmitter design with a large number of nodes to be decoded even if collisions occur.
- at the MAC layer a large number of solutions are designed, depending on the context and the application. The physical layer and the channel are usually approximately modelled.

The application we want to develop needs to support three different types of applications:

- regular information sensing and transmission, with an updating time depending on the type of data,
- transmission depending on a sudden change in the sensed data,
- urgent request from a user.

This introduces a mix on ultra-low power communications and low latency/high reliability situations. This project will be based on the previous work about MAC layer by V. Toldov, “Adaptive MAC layer for interference limited WSN,” Thèses, Université Lille 1 Sciences et technologies, Jan. 2017 (Available: https ://hal.inria.fr/tel-01493094). The goal is to design a MAC layer for LP-WAN (Low Power, Wide Area Networks) that supports the previously mentioned applications.