Fully funded PhD position (3 years, starting Sept./Oct. 2021): **Smart Energy Modeling and Management in battery-less embedded systems**

Key words: Ultra Low-Power architecture, Normally-off embedded systems, IoT, Energy Harvesting, Energy Models, Transient Computing

1 Scientific context

Faced with modern environmental challenges, the development of IoT needs to be conducted within a context of sobriety in design, energy efficiency, and sustainability. Focusing on the design of end-devices (i.e. the wireless sensors), this entails the combination of near-sensor computing and normally-off architectures [6]. In this model of computation (transient computing) the objective of the embedded architecture is to support power losses, as the system does not include a battery [1]. To make it efficient the system needs to support that complex computations can be distributed over several power cycles. It aims at significantly increasing the complexity of software running on these devices, and thus at reducing the volume of outgoing data, which improves the overall energy efficiency of the whole processing chain.

The purpose of the PhD thesis is to address run-time management of energy of an intermittent system. To that purpose, models of energy flows within the devices (energy consumed and harvested) will be proposed to pave the way for efficient implementation of complex software supporting power-loss. A proof of concept, implementing a bird sound recognition application, and running on the developed intermittent platform (on microcontroller with sensors and peripherals) will complete the proposed work.

2 Scientific issues

The main objective of this PhD work is to smartly model and manage energy in intermittent systems. This work takes place in the frame of the NOP project that proposes a whole framework for this computation model. The intended platform includes an ultra-low power processor core, powered-up by a harvesting system with a super-capacitor (i.e. no battery in the system) and is built around new Non-Volatile Memories (NVM) [2] that will be used for efficient *checkpointing* (save and restore) of current state of the processor for the anticipation of power-loss. The harvester (photo-voltaic panels in a first approach) will be included in the system to make it energy self sufficient. The framework will include an energy-oriented compiler, that will statically place *checkpoints* in the application according to an energy budget. The system is completed by an embedded operating-system (eOS) that will manage the platform at real-time according to the available energy, and the possible energy that could be harvested. This eOS will be in charge of proposing a model of intermittent tasks, and will manage the global execution of the platform according to the available energy.

In the framework of the project, this PhD subject concerns the proposal of the required energy models that will be used by the compiler and by the eOS. These models will consider both, the energy consumed by the device as well as energy harvested by the device. Additionally, the management of the energy in the system will rely on the harvesters and the management of the remaining and possible future harvested energy [3]. Besides the design of the hardware platform (based on off-the-shelf components) several main tasks for this PhD work are highlighted :

1. The first main task will be to address the energy consumption models of the device at different granularities : a) A fine-grain model at the instruction level. This information will be used in the NOP project by the compiler in order to determine optimal placement of *checkpoints* where the execution environment and variables will be stored in NVM. Additionally, this model will be used for the classical compilation phases like instruction choice in order to minimize the energy required by the program. The compiler study is out of the scope of this PhD, but will require close collaboration with the project partners. b) A coarse-grain model will extend this first energy consumption model in order to include hardware functioning modes supported by the hardware platform (low-power modes) and the hardware interfaces (front-end radio, sensors, ...) [5]. This coarse-grain model will feed an energy manager that will be able to take decisions at run-time in order to smartly manage the available energy at any time. This energy manager will be part of the eOS and will also require close collaboration with the project partners.

2. The second task will address the energy manager, by providing an energy harvesting model and propose adapted and efficient energy management algorithms. Models predicting the harvested energy, adapted to the source and the environment considered in this project (e.g., solar in a first approach), will be studied. According to the dynamic energy consumption and the harvested energy estimation, an energy budget will be then determined. The latter will be used at run-time in order to smartly select when it is necessary to execute a static checkpoint placed by the compiler or if it is possible to avoid it. Additionally this model and the associated manager will be used by the eOS to schedule tasks according to the remaining energy. For these objectives further enhancement techniques, for instance reward-based, will be investigated in order to enhance the decision of checkpointing [4] fire, or scheduling control insuring a safe progress of the program execution.

3. Finally, the developed methodology and the platform prototype will be used in a specific use-case that consists of the quasi-continuous sensing of the environment with a microphone to detect bird activities. The purpose of this task is to position the performance of the transient approach with respect to a more classical one where the device would not handle power losses. Different performance indicators will be assessed (functioning time, required energy, energy manager overhead, ...) and the trade-off between harvester dimensioning and quality of service will be demonstrated.

3 Candidate profile

The candidate must be able to demonstrate theoretical/practical knowledge in the areas of computer, architecture and embedded systems design. Additionally, skills in energy consumption of electronic devices and C programming are mandatory. Some knowledge or at least interest on compilation, checkpointing and embedded OS are of interest in the frame of NOP project. As approaches of learning methods could be used in the PhD, some knowledge would be a good asset.

Depending on the candidate native language, French or English will be the working language. Knowledge in French is not a prerequisite.

Applying candidates will prove and/or justify the requested knowledge and skills by providing:

- A CV;
- Academic records and transcripts of Master, or of the last year of Engineer school;
- All documents attesting the requested skills and knowledge.

4 PhD context

This PhD project is within the frame of Cominlabs[1] NOP (Normally Off Platforms) project that has been accepted for funding. In this project 2 PhDs and several master students will collaborate on the different topics. The successful candidate will do his/her research in Syscom team from IETR and GRANIT team from IRISA.

The Syscom research team from IETR has an important activity in ultra low power SoC energy constrained Embedded Systems design and management. Granit research team from IRISA lab at Lannion has recognized expertise in energy harvesting for IoT devices.

The candidate will be administratively registered in Nantes, France. Although this PhD will be held at Université de Nantes, several research period in Lannion within Granit team will be planned during the thesis.

The PhD candidate will be fully integrated (discussions, meetings, seminars) in the NOP project consortium, meetings and will collaborate with the other researchers and PhD/master students within the project. He/She may co-supervise internship students. He/She may have some opportunities for teaching (added to his payroll), if interested.

- **Research Laboratories:** IETR (UMR CNRS 6164) and IRISA UMR CNRS 6074)
- **University:** Polytech, Université de Nantes
- **Location:** IETR/Polytech, Nantes, FRANCE
- **Intended starting date:** September or October 2021 (3-year duration)

5 To apply

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Deadline for application : Applications will be considered as they arrive and until there is a successful candidate

6 References

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[1] label d'excellence