NOP: Safe and Efficient Intermittent Computing for a Batteryless IoT

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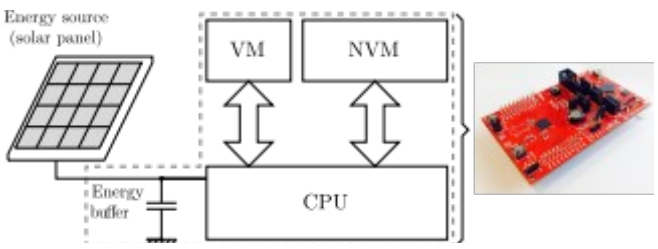
NOP in a nutshell

Batteryless design promises to push forward the limits of autonomy for IoT nodes.

However, ambient power harvesting yields to **intermittent availability** of the platform.

NOP aims to design SW stack + HW platforms for safe and efficient execution of services on fully autonomous intermittent IoT nodes, leveraging across all layers the concept of **energy-aware design**.

Workplan and past work



WP1: Energy models & management

WP2: Execution models

WP3: Proofs of Concepts

Safety guarantees

- Formal model based on extended Cost Time Petri Net + safe by construction scheduling [1,2]
- Static checkpointing with worst-case guarantees of forward progress [3,5]

Efficient computations

- Optimal scheduling [1], opportunistic runtime reclaiming unused energy [2]
- Joint checkpoint placement/memory allocation [3,5]

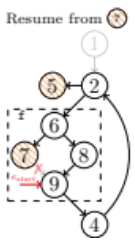
EarlyBird: Energy belongs to those who wake up early [4,5]

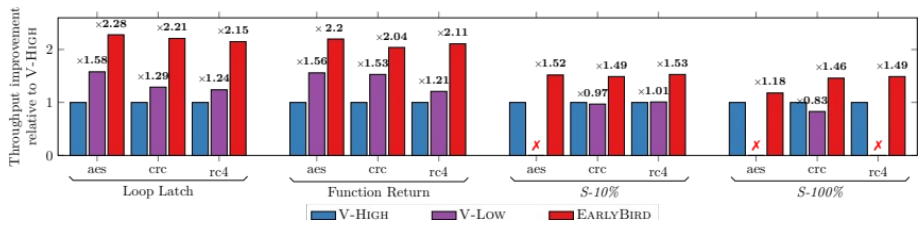
Lower operating voltage is more energy efficient. But low-energy threshold cannot guarantee forward progress of energy-intensive tasks.

→ **Runtime adaptation of wake-up voltage to energy requirements.**

Implementation & evaluation

- Computation of partial WCEC between two checkpoints, based on IPET.





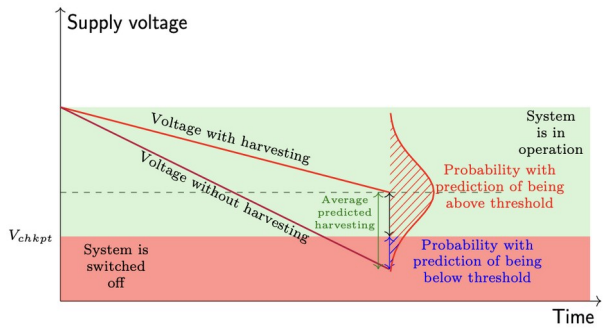
- Library for bare metal execution on MSP430FR5994.
- Reproducible experimental setup based on RF power supply.

BET: Beyond Energy Threshold

Worst-case = formally safe but sometimes inefficient.

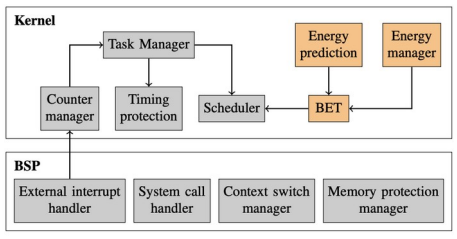
→ **Moving from formal to probabilistic guarantees**

Idea: bet on expected average power harvesting to escape the worst-case scenario.

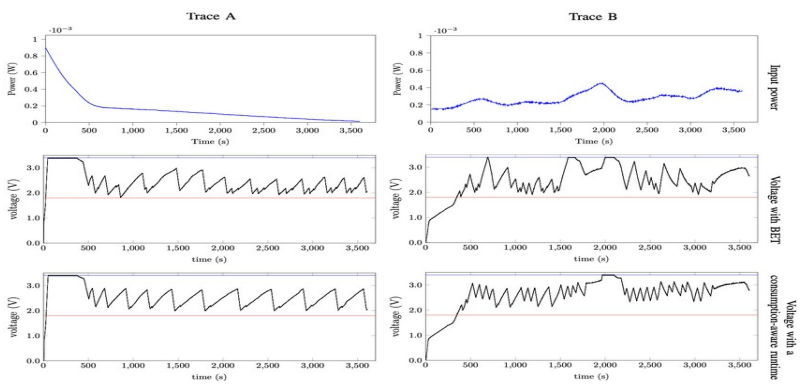


Implementation & evaluation

- Extension of Trampoline RTOS for MSP430FR5994



- Benchmark : simple DNN (task: MNIST)
- Experimental setup similar to EarlyBird



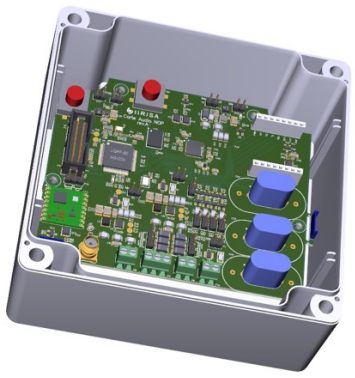
	Power trace A			Power trace B		
	with BET	without BET	Alpaca	with BET	without BET	Alpaca
# of inference completed	24	23	19	54	53	51
% of time in runtime	0.77	0.09	0.79	4.22	5.65	2.3
% of time in hibernation	73.614	76.21	79.581	43.44	45.08	41.34
Voltage RMS (V)	2.48	2.6	2.06	2.63	2.78	1.92

PoCs : BARD, NOP sensor node, CNN toolchain

BARD: batteryless IoT node built around off-the-shelf components, computes and sends acoustics indices in full autonomy.

NOP sensor node: batteryless IoT node integrating FPGA and external FRAM to execute ML workloads in full autonomy.

CNN toolchain: bridges the gap between high level description of DNN/CNN in Julia and embedded C code for batteryless IoT nodes.



Publications

[1] A. Bernabeu *et al.*, « *Cost-Optimal Timed Trace Synthesis for Scheduling of Intermittent Embedded Systems* ». In DEDS, vol 33, 2023.

[2] A. Bernabeu, « *Support d'exécution pour les systèmes intermittents* ». Thèse de doctorat, École Centrale Nantes, 2023.

[3] H. Reymond *et al.*, « *SCHEMATIC : Compile-time checkpoint placement and memory allocation for intermittent systems* ». In IEEE/ACM CGO, 2024.

[4] H. Reymond *et al.*, « *EarlyBird : Energy belongs to those who wake up early* ». In IEEE RTCSA, 2024. **Best paper award**

[5] H. Reymond, « *Modèle d'exécution conscient de l'énergie pour les systèmes intermittents* ». Thèse de doctorat, Université de Rennes, 2024.