Modeling Battery-free Communications for the Cooja Simulator

Carlos Pérez-Penichet, Georgios Daglaridis, Dilushi Piumwardane, Thiemo Voigt

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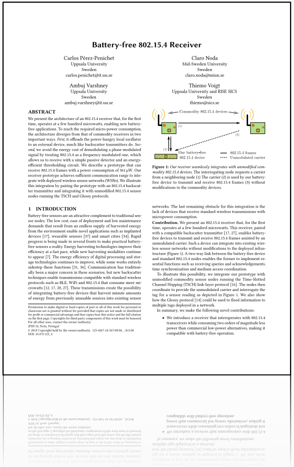

Battery-free 802.15.4 Receiver

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ABSTRACT

We present the architecture of an 802.15.4 receiver that, for the first time, operates at a few hundred microwatts, enabling new battery-free applications. To reach the required micro-power consumption, the architecture diverges from that of commodity receivers in two important ways. *First*, it offloads the power-hungry local oscillator to an external device, much like backscatter transmitters do. *Second*, we avoid the energy cost of demodulating a phase-modulated signal by treating 802.15.4 as a frequency-modulated one, which allows us to receive with a simple passive detector and an energy-efficient thresholding circuit. We describe a prototype that can receive 802.15.4 frames with a power consumption of 361 μW. Our receiver prototype achieves sufficient communication range to integrate with deployed wireless sensor networks (WSNs). We illustrate this integration by pairing the prototype with an 802.15.4 backscatter transmitter and integrating it with unmodified 802.15.4 sensor nodes running the TSCH and Glossy protocols.

Figure 1: *Our receiver seamlessly integrates with unmodified commodity 802.15.4 devices.* The interrogating node requests a carrier from a neighboring node (1) The carrier (2) is used by our battery-free device to transmit and receive 802.15.4 frames (3) without modifications to the commodity devices.

1 INTRODUCTION

Battery-free sensors are an attractive complement to traditional sensor nodes. The low cost, ease of deployment and low maintenance demands that result from an endless supply of harvested energy from the environment enable novel applications such as implanted devices [17], wearable sensors [37] and smart cities [34]. Rapid progress is being made in several fronts to make practical battery-free sensors a reality. Energy harvesting technologies improve their efficiency at a fast pace, while new harvesting modalities continue to appear [7]. The energy efficiency of digital processing and storage technologies continues to improve, while some works entirely sidestep these functions [31, 36]. Communication has traditionally been a major concern in these scenarios, but new backscatter techniques enable transmissions compatible with standard wireless protocols such as BLE, WiFi and 802.15.4 that consume mere microwatts [12, 17, 20, 27]. These transmissions create the possibility of integrating battery-free devices that harvest minute amounts of energy from previously unusable sources into existing sensor networks. The last remaining obstacle for this integration is the lack of devices that receive standard wireless transmissions with micropower consumption.

Contribution. We present an 802.15.4 receiver that, for the first time, operates at a few hundred microwatts. This receiver, paired with a compatible backscatter transmitter [17, 27], enables battery-free devices to transmit and receive 802.15.4 frames assisted by an unmodulated carrier. Such a device can integrate into existing wireless sensor networks without modifications to the deployed infrastructure (Figure 1). A two-way link between the battery-free device and standard 802.15.4 nodes enables the former to implement essential functions such as receiving queries and acknowledgements, time synchronization and medium access coordination.

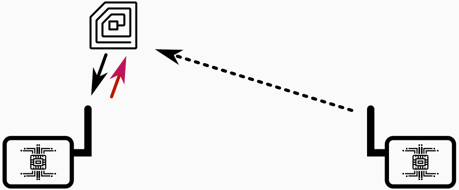
To illustrate this possibility, we integrate our prototype with unmodified commodity sensor nodes running the Time-Slotted Channel Hopping (TSCH) link-layer protocol [16]. The nodes then coordinate to provide the unmodulated carrier and interrogate the tag for a sensor reading as depicted in Figure 1. We also show how the Glossy protocol [14] could be used to flood information to multiple tags deployed in a network.

In summary, we make the following novel contributions:

- We introduce a receiver that interoperates with 802.15.4 transceivers while consuming two orders of magnitude less power than commercial low-power alternatives, making it compatible with battery-free operation.

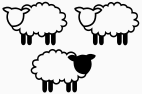
IPSN'18, Porto, Portugal

DOI: 10.475/123_4



Carlos Pérez-Penichet, Claro Noda, Ambuj Varshney, and Thiemo Voigt. In *ACM/IEEE IPSN 2018*

A Simulator is Useful



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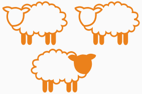  

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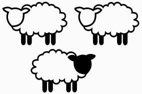

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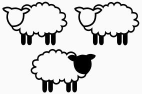
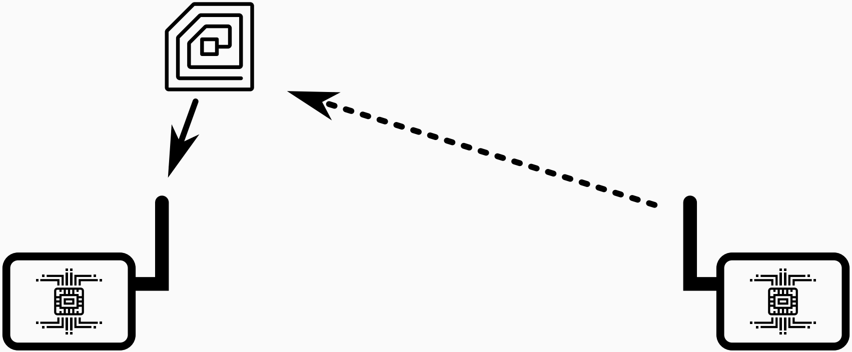


New Models for Carrier-Assisted Communications

1. Simple but realistic models inspired by experiments
2. Implement our models in the Cooja simulator
3. Illustrate how such a tool can be useful



Employ External Carrier to Transmit and Receive



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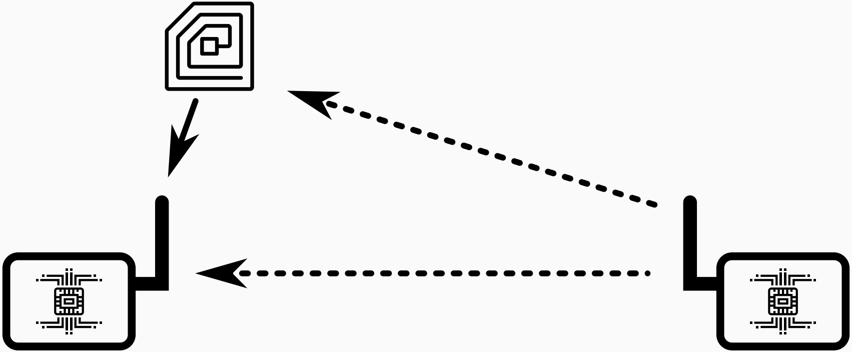

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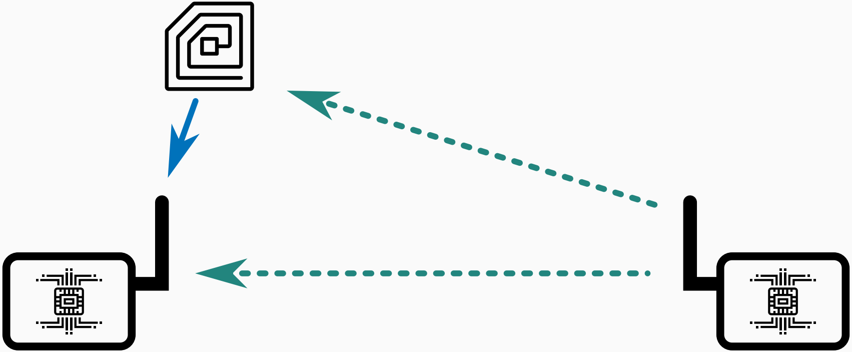

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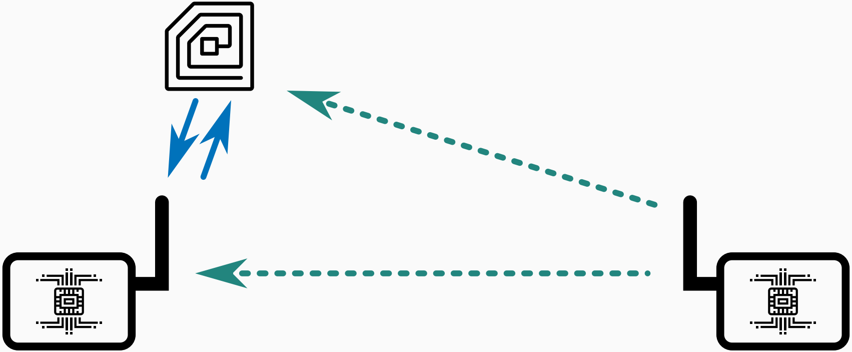
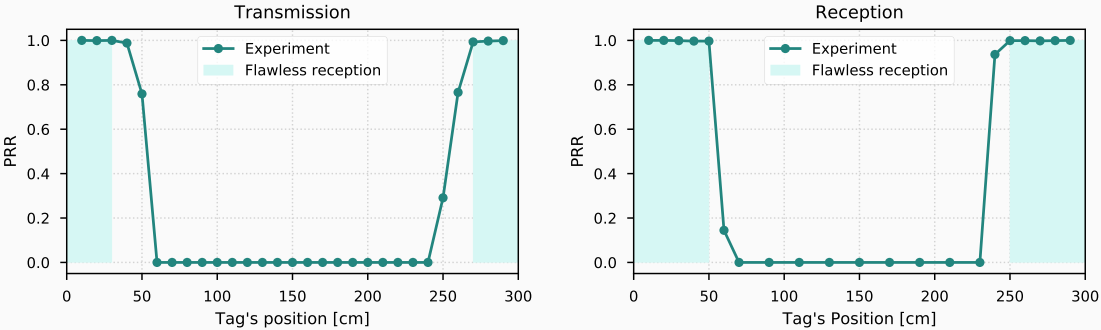
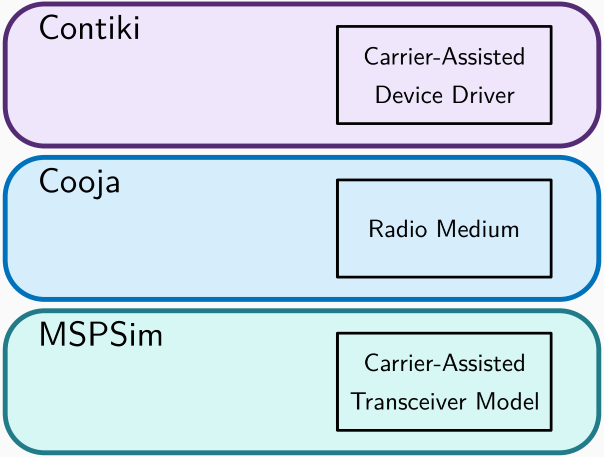


Two Zones of Flawless Reception



Cooja Implementation



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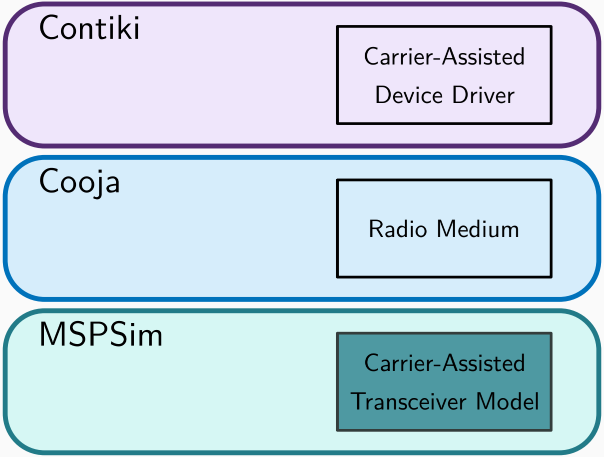
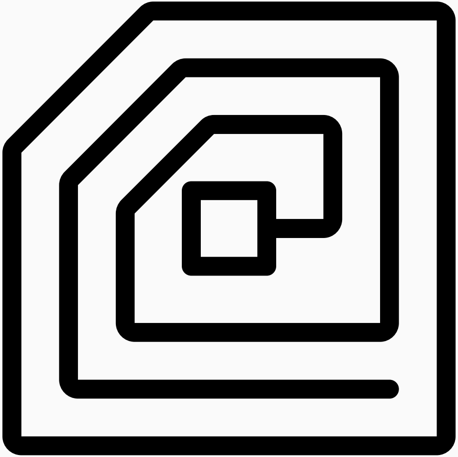


Carrier Assisted Device Model



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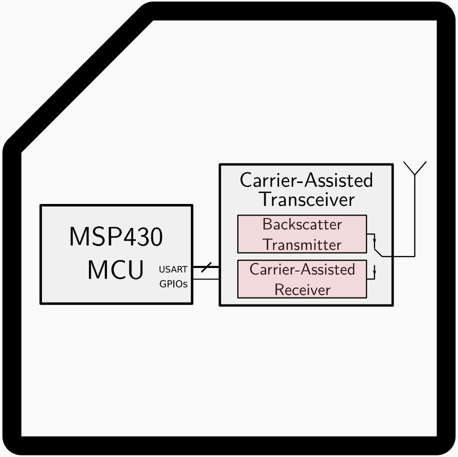

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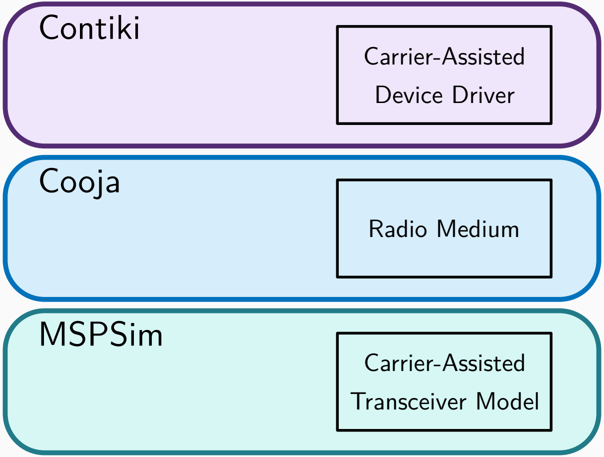

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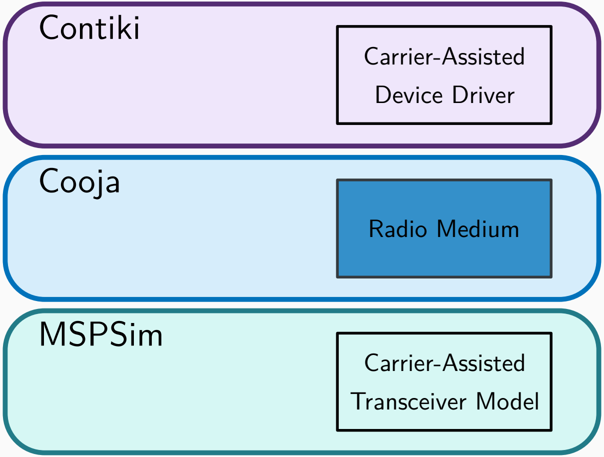

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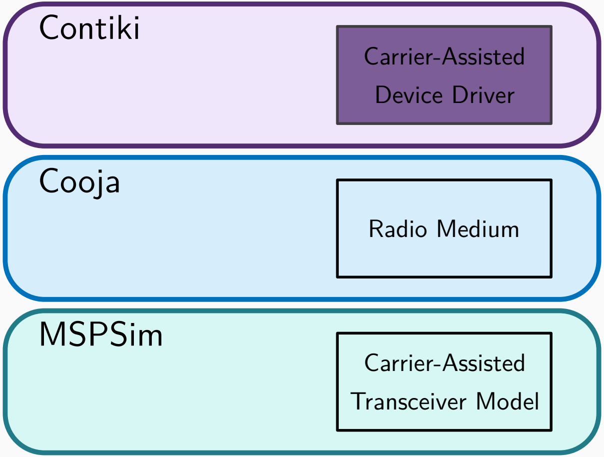
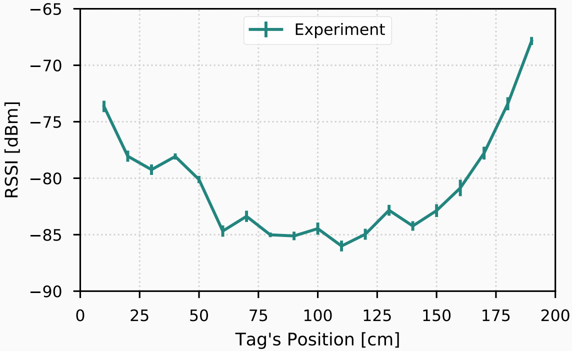


Radar Range Equation



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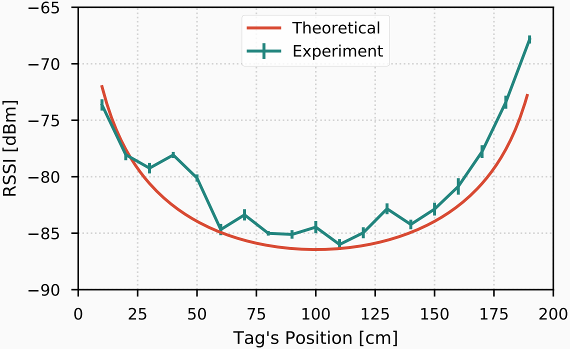

$$P_r = \left(\frac{\lambda^2 P_t G_t}{16\pi^2 R_1^2}\right)\left(G_b^2 \alpha \frac{|\Delta\Gamma|^2}{4}\right)\left(\frac{\lambda^2 G_r}{16\pi^2 R_2^2}\right)$$

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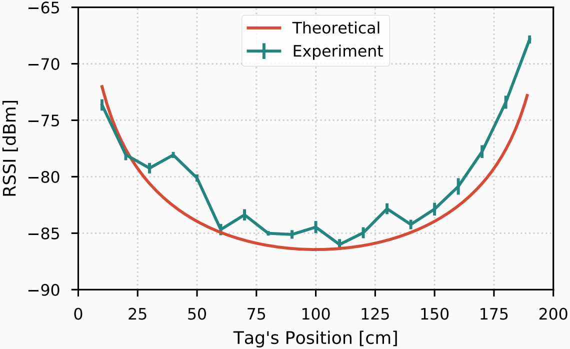

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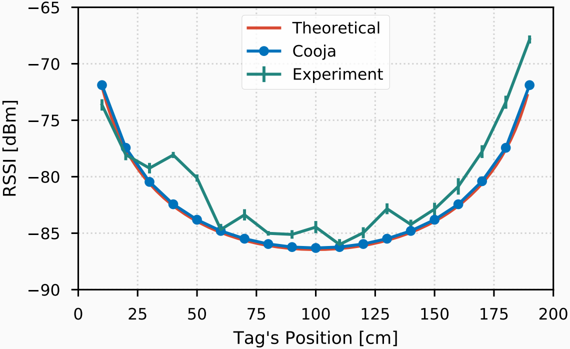

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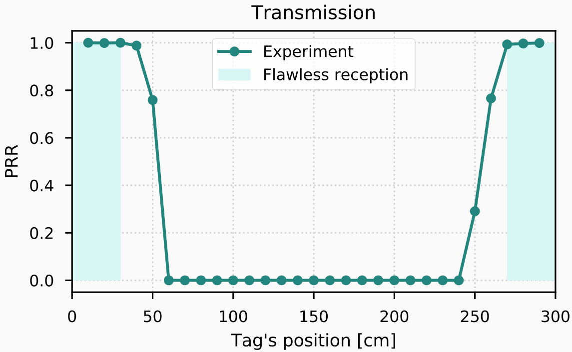

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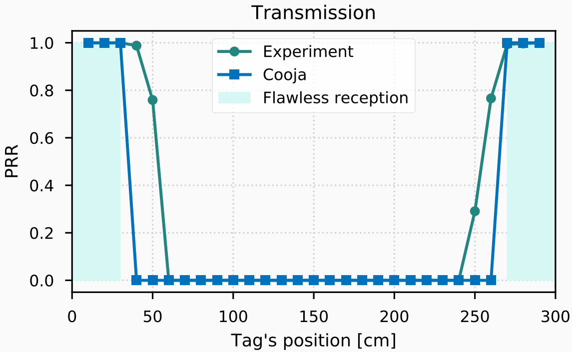
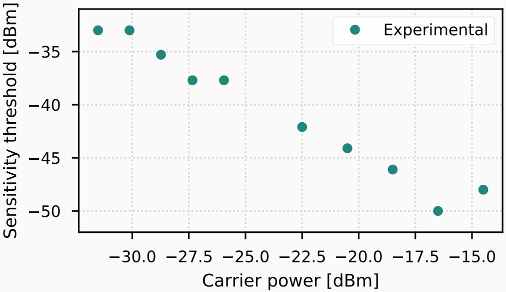


Receiver Sensitivity Depends on Carrier Strength



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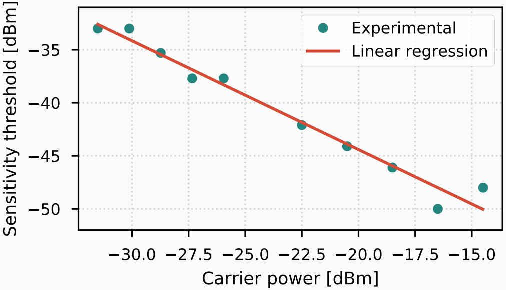
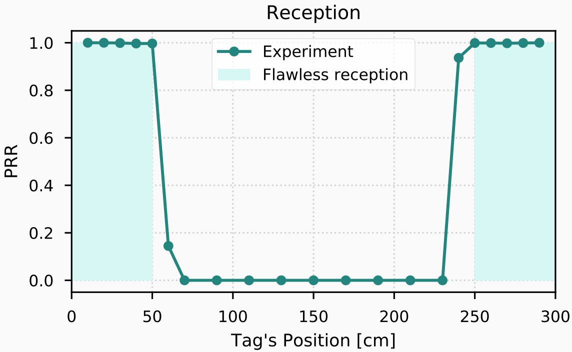


Two Zones of Flawless Reception (Receiver edition)



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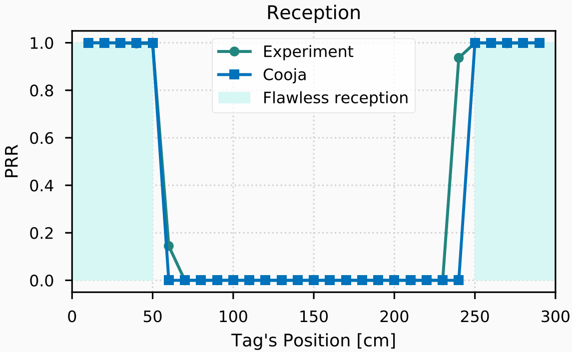
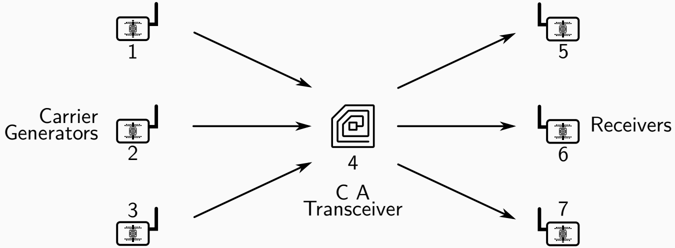
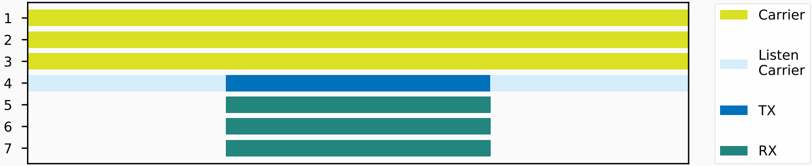


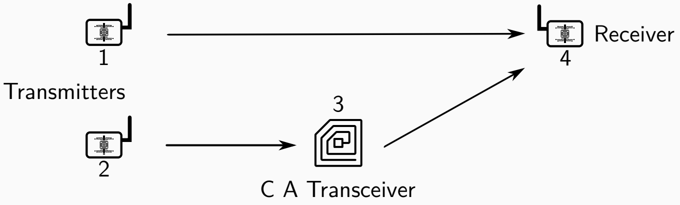
Multi-carrier Backscatter





Varshney et al. In *ACM SenSys 2017*

Reflection Interference



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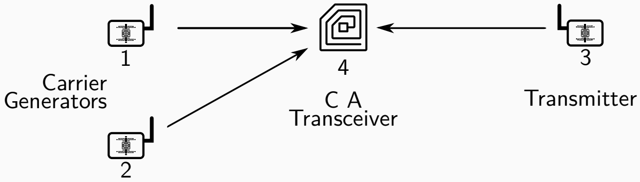
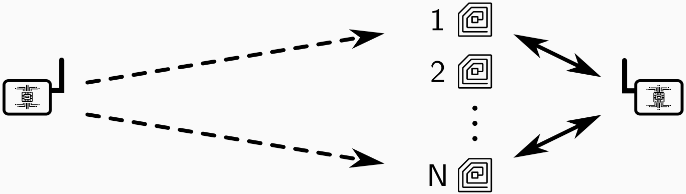
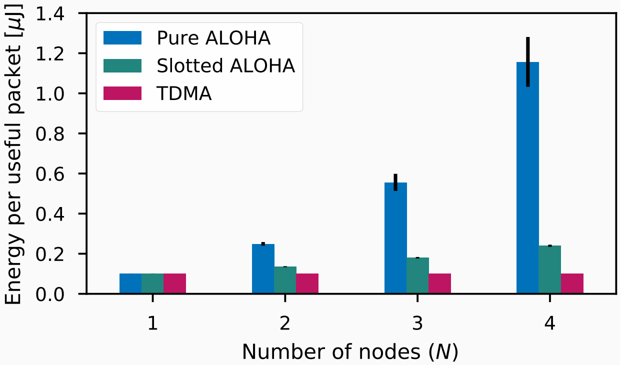


Sensor Tag Scenario



Evaluating Protocols' Energy Consumption



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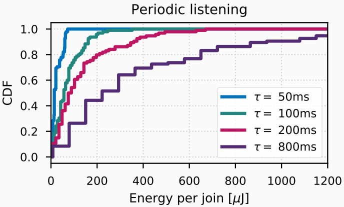

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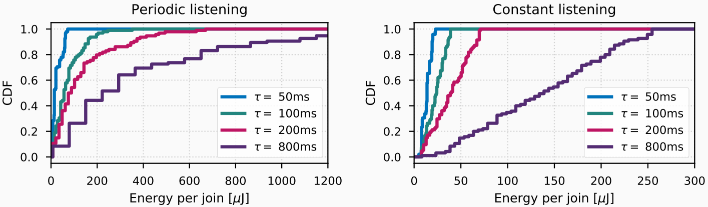

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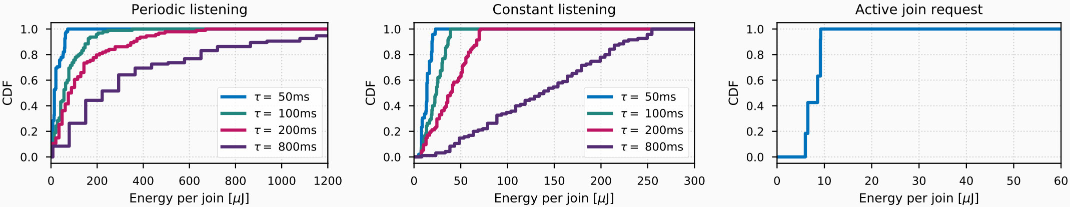

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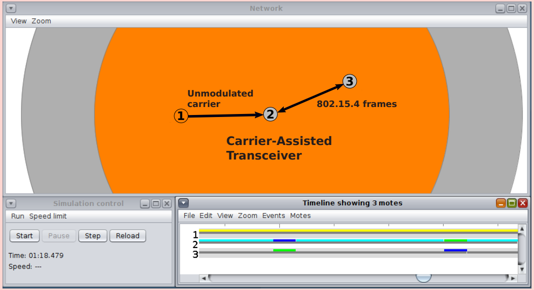
Available Today



https://github.com/cperezpenichet/contiki-ng/tree/carrier-assisted

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