Achievement #3: Distributed Battery-Free Systems

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In an era of climate change and an ever-increasing demand for trillions of new Internet of Things (IoT) devices, ensuring the sustainability of the IoT is one of today's grand challenges. Batteries are a major concern as they require maintenance and incur huge environmental costs.[1] Battery-free devices promise a sustainable IoT by harvesting energy from renewable sources and using maintenance-free, eco-friendly capacitors as energy storage. Relying on volatile harvested energy, however, makes operation intermittent: the devices frequently lose power and need to recharge to resume operation, as illustrated in Figure 1. While it is known how to deal with these interruptions on a *single* device, it is still unclear how to communicate between and coordinate *multiple* battery-free, intermittent devices. This gap prevents industry and society from leveraging the benefits of the IoT while meeting our sustainability goals.

[1] ONiO. The massive environmental cost of batteries, 2020. URL `https://www.onio.com/article/environmental-cost-of-batteries.html`

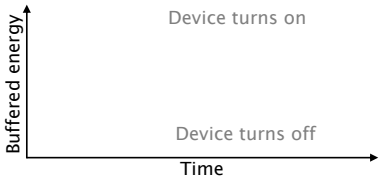

Figure 1: Frequent, seemingly unpredictable power failures (aka intermittency) make efficient and reliable sensing, actuation, computing, and communication between battery-free devices major scientific challenges.

We have successfully started to address this gap. We solved the two fundamental problems of neighbor discovery and synchronization in a distributed battery-free system. Using these solutions to bootstrap communication, we further developed the first protocol that maintains a long-running connection between two battery-free devices against intermittency patterns that vary across time and space. To enable this research, we developed and open-sourced the first tool to gain unprecedented insights by recording (and replaying) harvesting power synchronously at high rate and resolution across many distributed battery-free devices. Based on these initial results and prototypes (see Figure 2), we will continue pushing the state of the art in embedded machine learning, wireless networking, and cyber-physical systems to make the IoT truly sustainable.

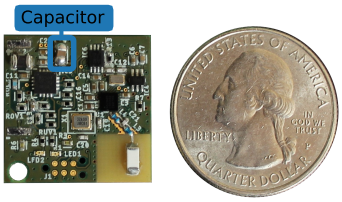

Figure 2: Battery-free hardware prototype based on the nRF52805 microcontroller. A sustainable 3.1 mm^3 ceramic capacitor is used as energy storage.

Academic and Real-World Impact

Our research on battery-free and energy-harvesting systems has led to publications at top-tier conferences in networking and embedded sensing, one of which was recognized by the NSDI Community Award. Small-scale case studies based on our prototypes have already shown the potential of our solutions for relevant applications, including automatic contact tracing and occupancy monitoring.

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