Achievement #3: Distributed Battery-Free Systems

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The proliferation of cyber-physical systems (CPS), vital for industries and societal advancements, relies on wireless networks with untethered power sources, allowing embedded devices to operate in remote or inaccessible locations. Batteries, with their limited lifespan and environmental impact, hinder scalability as replacing billions of batteries would be untenable and antithetical to the very sustainability efforts CPS are aiming to support.[1] Battery-free technology promises zero-maintenance embedded sensing powered entirely by energy derived from renewable sources, such as solar and vibrations. Relying on volatile harvested energy, however, makes operation intermittent: the devices frequently lose power and need to recharge to resume operation. While it is known how to deal with these non-deterministic interruptions on a single device, it is still an open problem how to network and exploit groups of multiple battery-free devices, preventing their adoption in CPS.

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

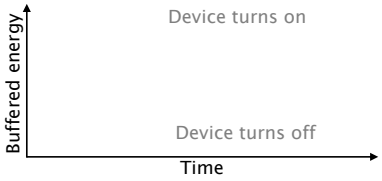

Figure 1: Frequent, seemingly unpredictable power failures (aka intermittency) make efficient and reliable sensing, actuation, computing, and communication between battery-free devices major scientific challenges.

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, and designed 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 and foster community growth, we developed the first tool to record harvesting power synchronously with high rate and resolution across many distributed battery-free devices, the first general-purpose battery-free hardware and software platform that is also commercially available, and the first public testbed that can consistently replicate real spatio-temporal energy environments. Based on our foundational work (see Figure 2), we will continue pushing the state of the art in embedded machine learning, wireless networking, and energy-harvesting systems to make CPS sustainable and resilient.

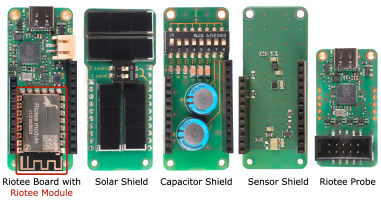

Figure 2: The Riotee battery-free platform features a stamp-sized reflow-solderable module, a user-friendly development board, three expansion shields, and a probe for in-circuit programming and debugging.

Academic and Real-World Impact

Our research on distributed battery-free systems has led to publications at top-tier conferences in mobile systems, 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. Moreover, we have commercialized our work on Riotee, the first general-purpose battery-free hardware-software platform that is fully open source and also available for sale, fostering community growth and reproducible research in battery-free systems.

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