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EWSN'24 Sustainability Competition

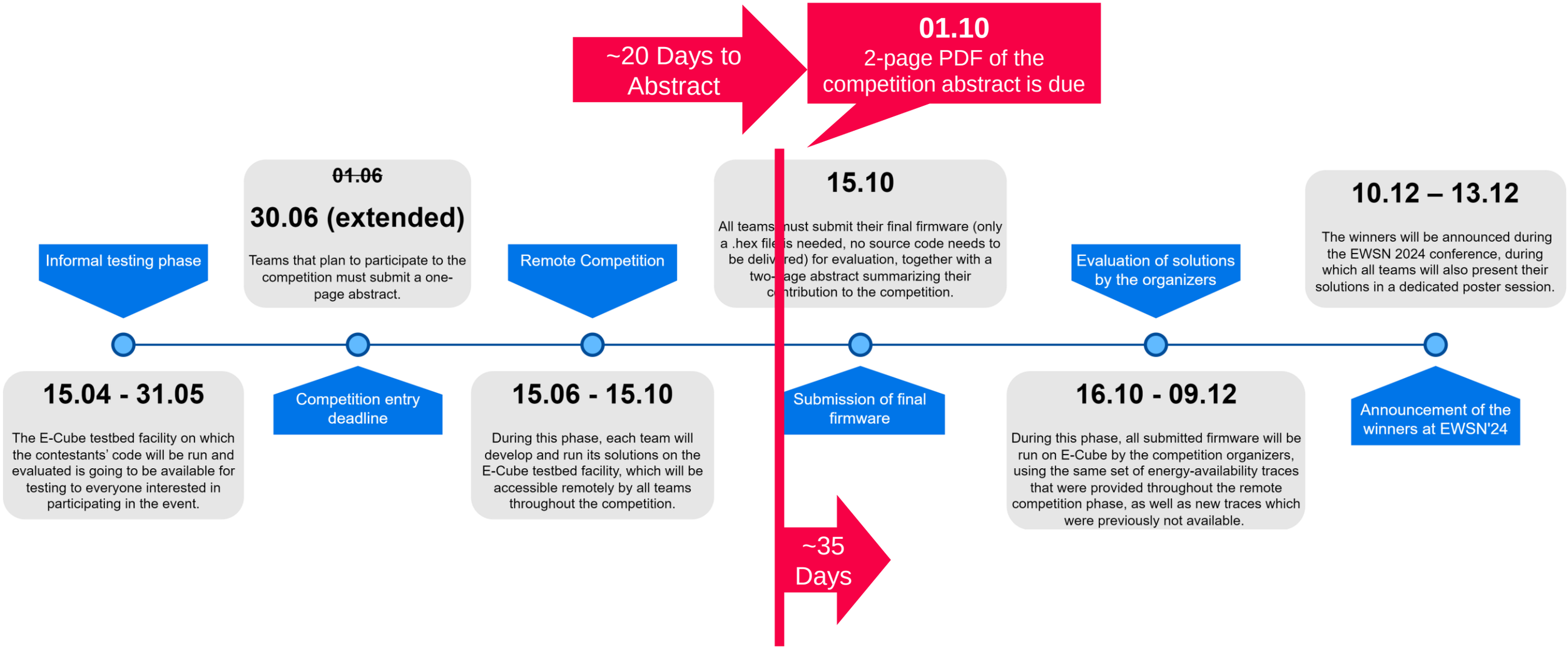
Community Meetup

Dr. Markus Schuß

Low-power Embedded Networked Systems (LENS) group
Graz University of Technology, Austria

10.09.2024

Timeline and Important Dates

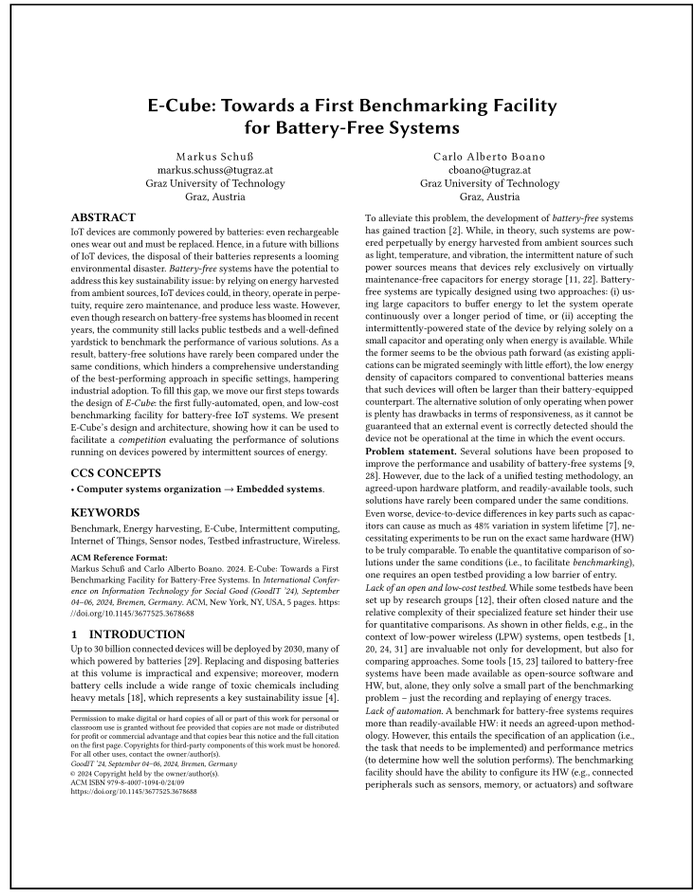


Abstract Deadline is very close!

- **Do not forget to submit your abstract by 01.10.2024**
  (In case your approach changes, you can still adapt it)

- A publication about E-Cube can be found in the GoodIT'24 proceedings published in the ACM digital library (see E-Cube website).

→ If you refer to E-Cube in your scientific work, please cite it



E-Cube: Towards a First Benchmarking Facility for Battery-Free Systems

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ABSTRACT

IoT devices are commonly powered by batteries: even rechargeable ones wear out and must be replaced. Hence, in a future with billions of IoT devices, the disposal of their batteries represents a looming environmental disaster. *Battery-free* systems have the potential to address this key sustainability issue: by relying on energy harvested from ambient sources, IoT devices could, in theory, operate in perpetuity, require zero maintenance, and produce less waste. However, even though research on battery-free systems has bloomed in recent years, the community still lacks public testbeds and a well-defined yardstick to benchmark the performance of various solutions. As a result, battery-free solutions have rarely been compared under the same conditions, which hinders a comprehensive understanding of the best-performing approach in specific settings, hampering industrial adoption. To fill this gap, we move our first steps towards the design of *E-Cube*: the first fully-automated, open, and low-cost benchmarking facility for battery-free IoT systems. We present E-Cube's design and architecture, showing how it can be used to facilitate a *competition* evaluating the performance of solutions running on devices powered by intermittent sources of energy.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**.

KEYWORDS

Benchmark, Energy harvesting, E-Cube, Intermittent computing, Internet of Things, Sensor nodes, Testbed infrastructure, Wireless.

ACM Reference Format:
Markus Schuß and Carlo Alberto Boano. 2024. E-Cube: Towards a First Benchmarking Facility for Battery-Free Systems. In *International Conference on Information Technology for Social Good (GoodIT '24), September 04–06, 2024, Bremen, Germany.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3677525.3678688

1 INTRODUCTION

Up to 30 billion connected devices will be deployed by 2030, many of which powered by batteries [29]. Replacing and disposing batteries at this volume is impractical and expensive; moreover, modern battery cells include a wide range of toxic chemicals including heavy metals [18], which represents a key sustainability issue [4].

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To alleviate this problem, the development of *battery-free* systems has gained traction [2]. While, in theory, such systems are powered perpetually by energy harvested from ambient sources such as light, temperature, and vibration, the intermittent nature of such power sources means that devices rely exclusively on virtually maintenance-free capacitors for energy storage [11, 22]. Battery-free systems are typically designed using two approaches: (i) using large capacitors to buffer energy to let the system operate continuously over a longer period of time, or (ii) accepting the intermittently-powered state of the device by relying solely on a small capacitor and operating only when energy is available. While the former seems to be the obvious path forward (as existing applications can be migrated seemingly with little effort), the low energy density of capacitors compared to conventional batteries means that such devices will often be larger than their battery-equipped counterpart. The alternative solution of only operating when power is plenty has drawbacks in terms of responsiveness, as it cannot be guaranteed that an external event is correctly detected should the device not be operational at the time in which the event occurs.

Problem statement. Several solutions have been proposed to improve the performance and usability of battery-free systems [9, 28]. However, due to the lack of a unified testing methodology, an agreed-upon hardware platform, and readily-available tools, such solutions have rarely been compared under the same conditions. Even worse, device-to-device differences in key parts such as capacitors can cause as much as 48% variation in system lifetime [7], necessitating experiments to be run on the exact same hardware (HW) to be truly comparable. To enable the quantitative comparison of solutions under the same conditions (i.e., to facilitate *benchmarking*), one requires an open testbed providing a low barrier of entry.

Lack of an open and low-cost testbed. While some testbeds have been set up by research groups [12], their often closed nature and the relative complexity of their specialized feature set hinder their use for quantitative comparisons. As shown in other fields, e.g., in the context of low-power wireless (LPW) systems, open testbeds [1, 20, 24, 31] are invaluable not only for development, but also for comparing approaches. Some tools [15, 23] tailored to battery-free systems have been made available as open-source software and HW, but, alone, they only solve a small part of the benchmarking problem – just the recording and replaying of energy traces.

Lack of automation. A benchmark for battery-free systems requires more than readily-available HW: it needs an agreed-upon methodology. However, this entails the specification of an application (i.e., the task that needs to be implemented) and performance metrics (to determine how well the solution performs). The benchmarking facility should have the ability to configure its HW (e.g., connected peripherals such as sensors, memory, or actuators) and software

Is [xyz] allowed

- Several unique takes on hashcash have been implemented...
  - The goal of the competition is to show battery-free operation
  - Unless the solution uses a clear sign of cheating (e.g., faking specific fields like the difficulty or cheating by exploiting a bug in the script)

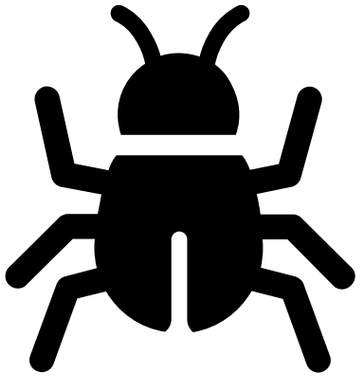
  → “Optimisations” of the format are allowed

- There is no way we can check which frequency you are using
  - Please avoid settings that permanently damage the board

  → Changing frequency is allowed

uSMU Accuracy/Timing

- Timing for very fast Energy Traces seems to be off
  - Will investigate this week, likely due to too high update rate
  - Super Capacitor traces may change (will notify via Discord)



Contacts

- E-Cube is being improved and upgraded on-the-go!
- We look forward to interact with you!
- Questions? Feedback?
  - https://discord.gg/baBP2GbUvb
    Feel free to hang out and exchange ideas!
  - markus.schuss@tugraz.at
- Other general inquiries?
  - ecube@iti.tugraz.at