

FUSIONCLOCK: Energy-Optimal Clock-Tree Reconfigurations for Energy-Constrained Real-Time Systems

28th September 2023 at FGBS-Herbsttreffen 2023

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Supported by the DFG under the grant WA 5186/1-1 (Watwa)

Paper appears in 35th Euromicro Conference on Real-Time Systems (ECRTS'23):

<https://doi.org/10.4230/LIPIcs.ECRTS.2023.6>



Lehrstuhl für Verteilte Systeme
und Betriebssysteme



Friedrich-Alexander-Universität
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Application Scenarios



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- embedded real-time systems: worst-case execution time (WCET), worst-case energy consumption (WCEC)

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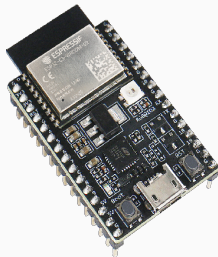
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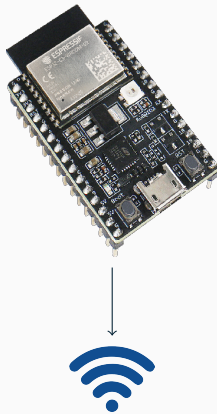


- embedded real-time systems: worst-case execution time (WCET), worst-case energy consumption (WCEC)
- devices massively influence timing and energy behaviour
⇒ reduce energy consumption for longer battery life

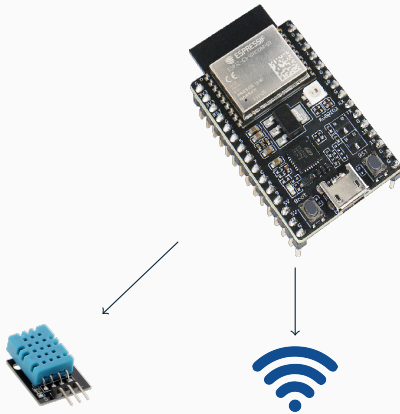
Devices on Embedded Systems



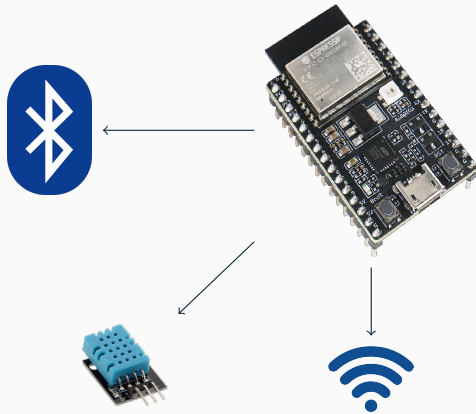
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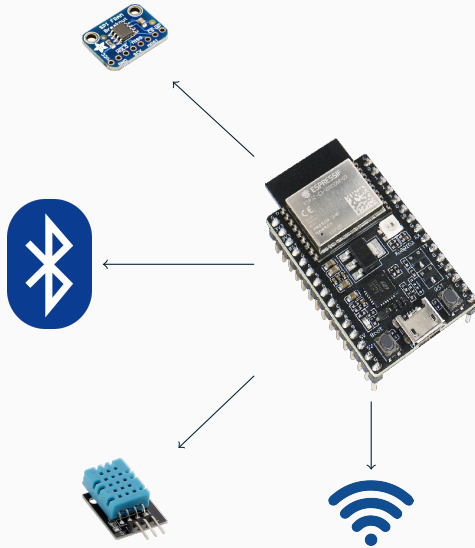
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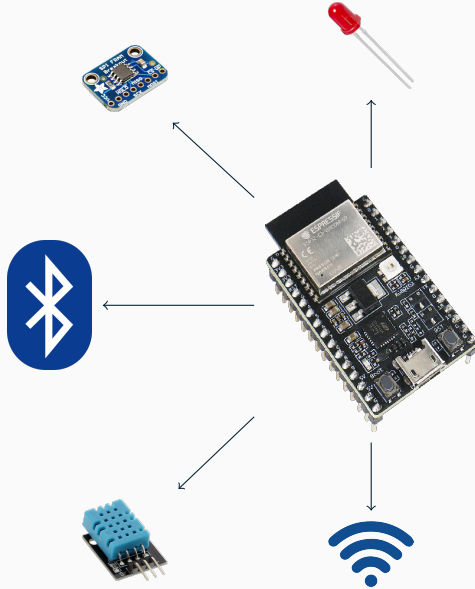
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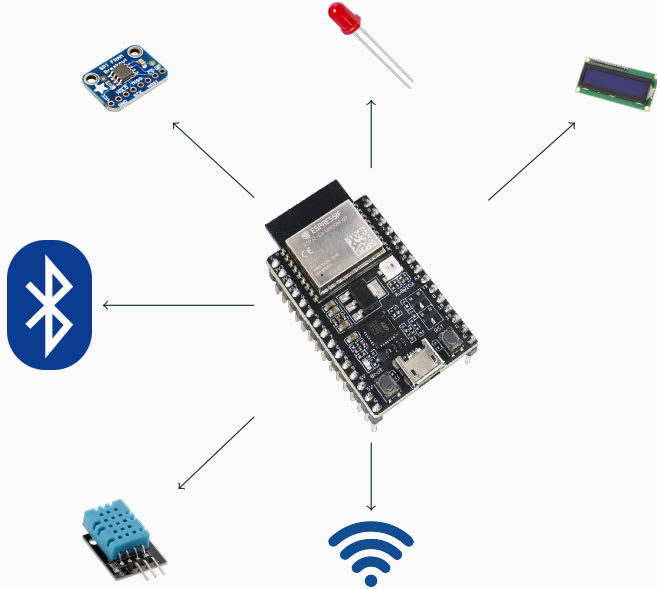
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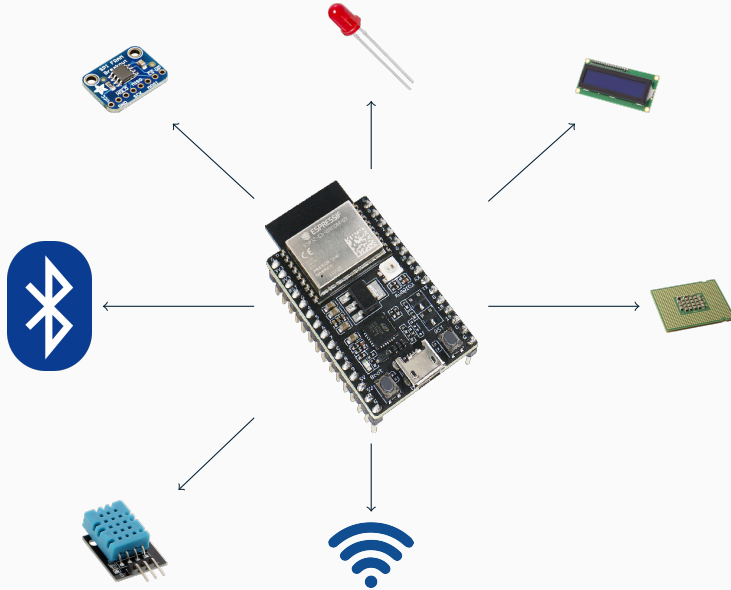
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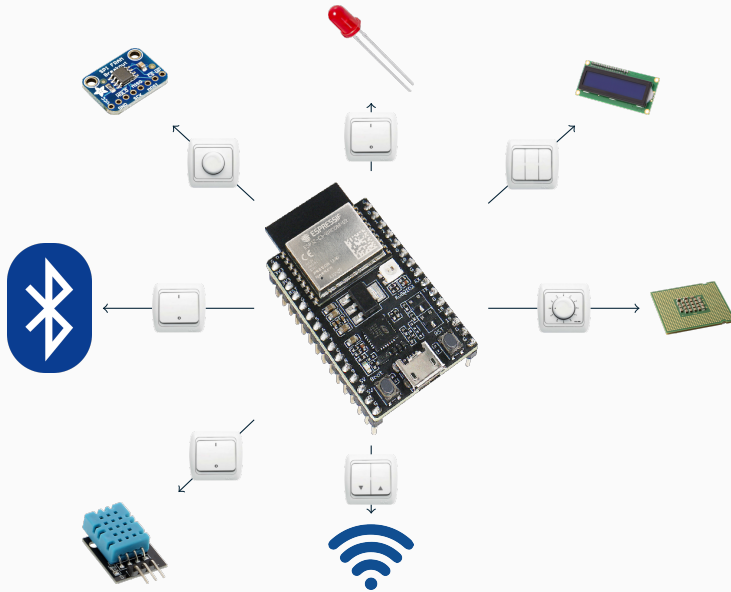
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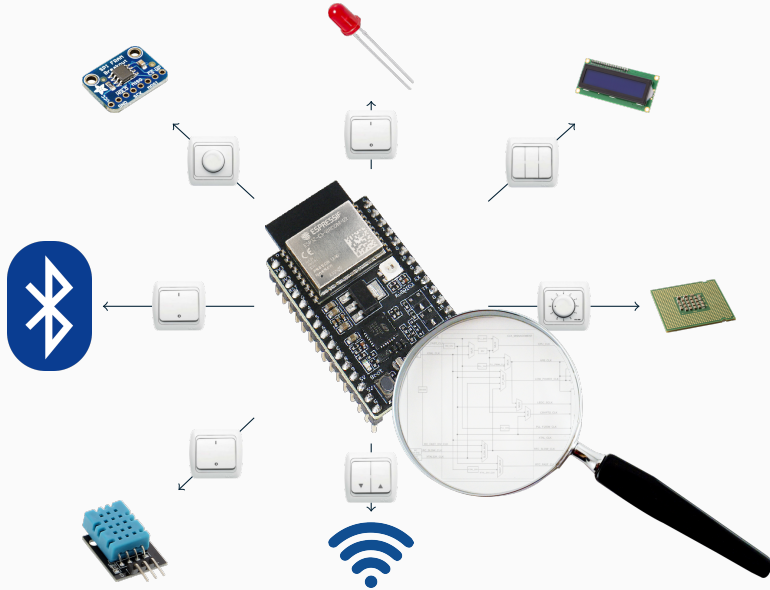
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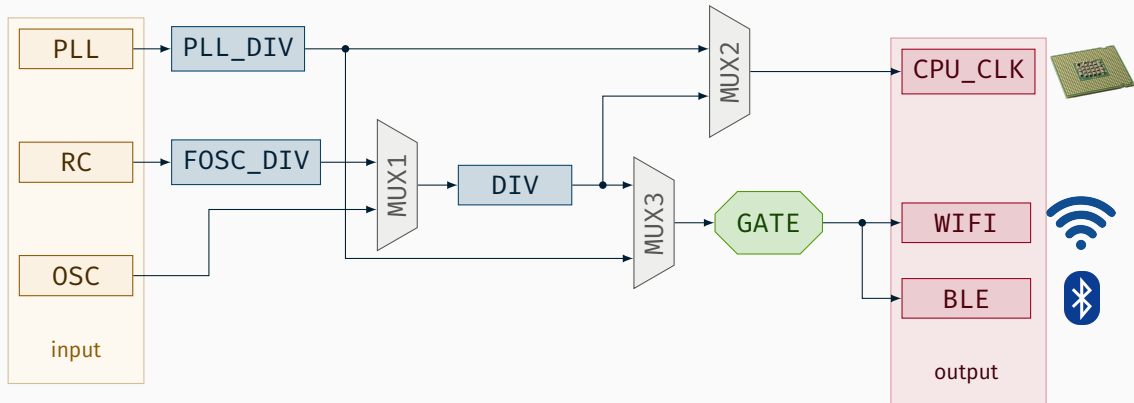
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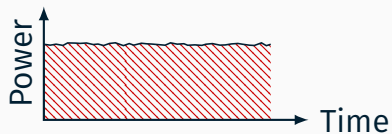
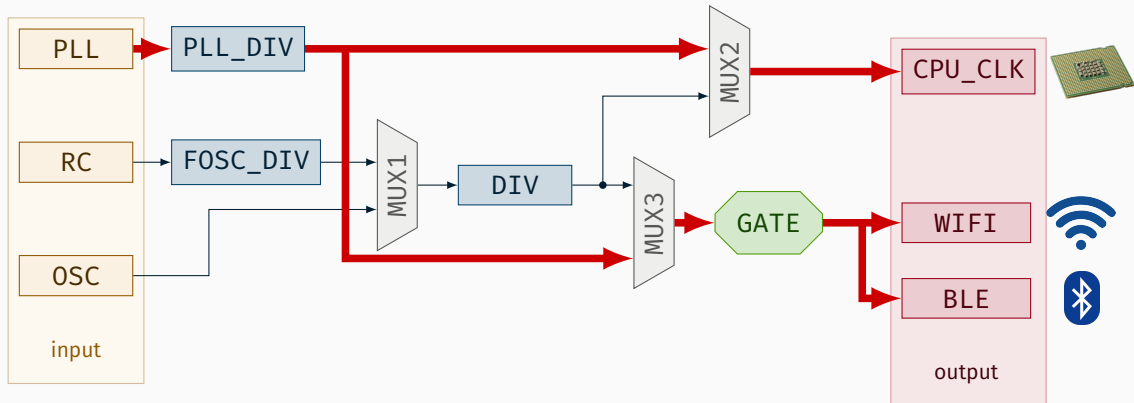
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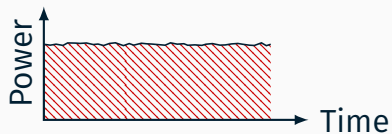
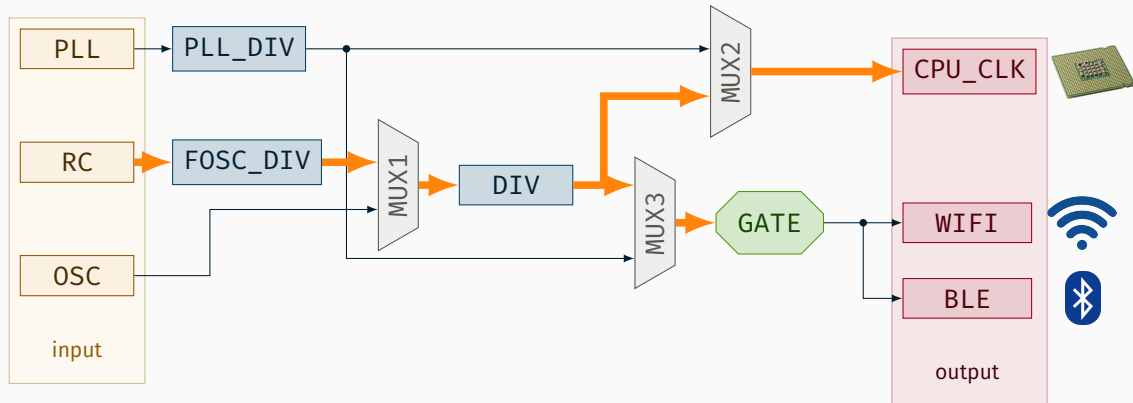
The Clock Tree



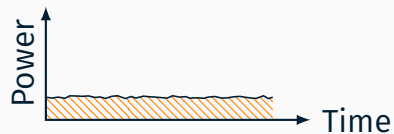
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The Clock Tree



v.s.



Problem Description

- single-core platforms

System Model / Requirements for FUSIONCLOCK

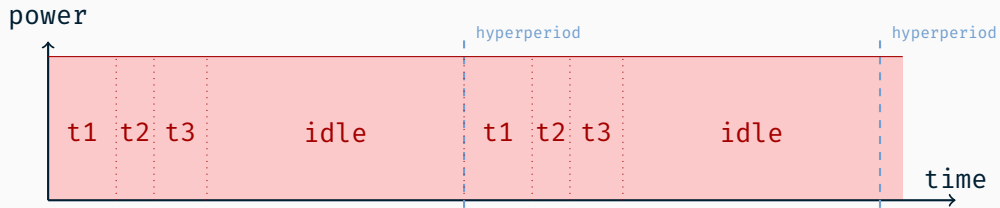
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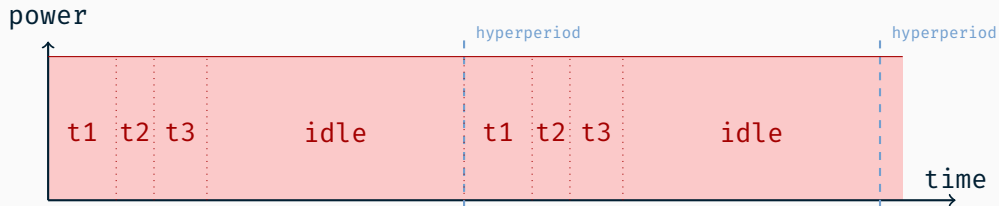
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 - including the **devices** of the system
- strictly periodic, cyclic task model
 - **time-triggered schedule**

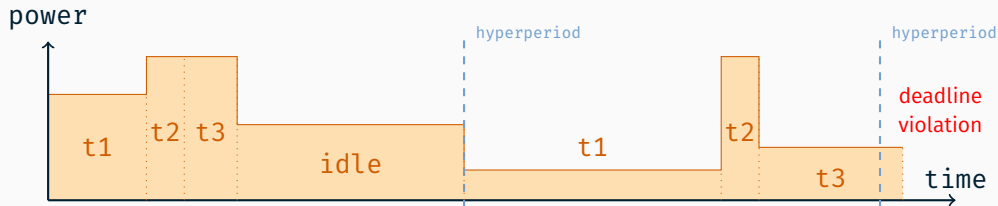


all-always-on approach



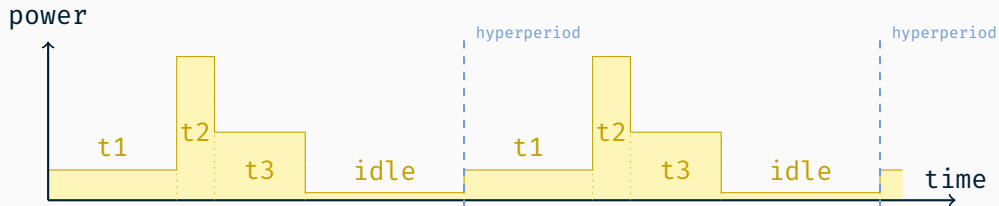
all-always-on approach

× minimization of energy consumption



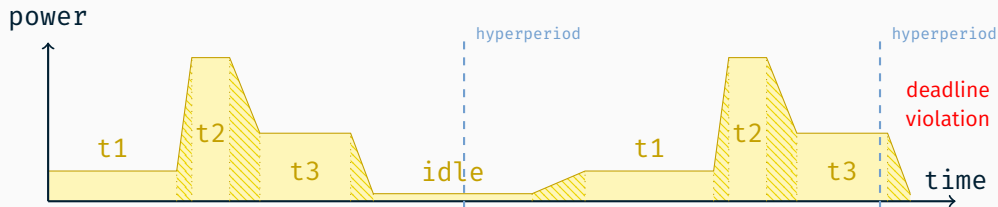
feedback-based approach: reconfigurations during execution

- minimization of energy consumption
- × real-time guarantees



static approach: analysis before execution

- minimization of energy consumption
- real-time guarantees

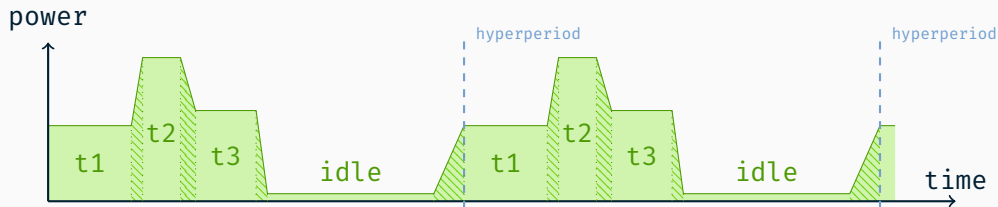


static approach without reconfiguration penalties

- minimization of energy consumption
- × real-time guarantees
- × consideration of reconfiguration costs

1. CPU-only approaches...
 - neglect energy consumption of **devices**
 - ignore **dependencies of devices** and **clock-tree configurations**
2. **no guarantees** of feedback-based approaches
3. missing **reconfiguration penalties**

Concept of FUSIONCLOCK



static approach with reconfiguration penalties

- ✓ minimization of energy consumption
- ✓ real-time guarantees
- ✓ consideration of reconfiguration costs

The FUSIONCLOCK **Approach**

Overview over the FUSIONCLOCK Approach

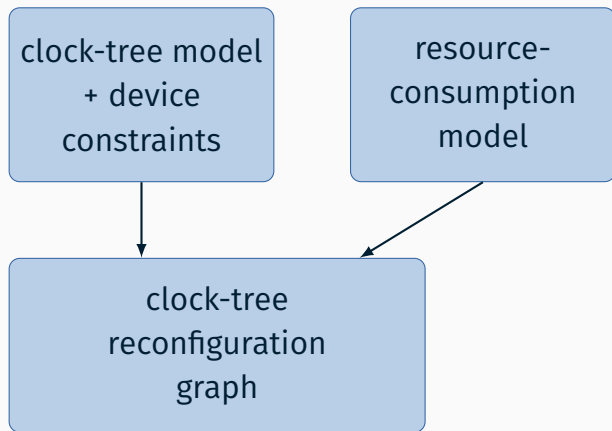
clock-tree model
+ device
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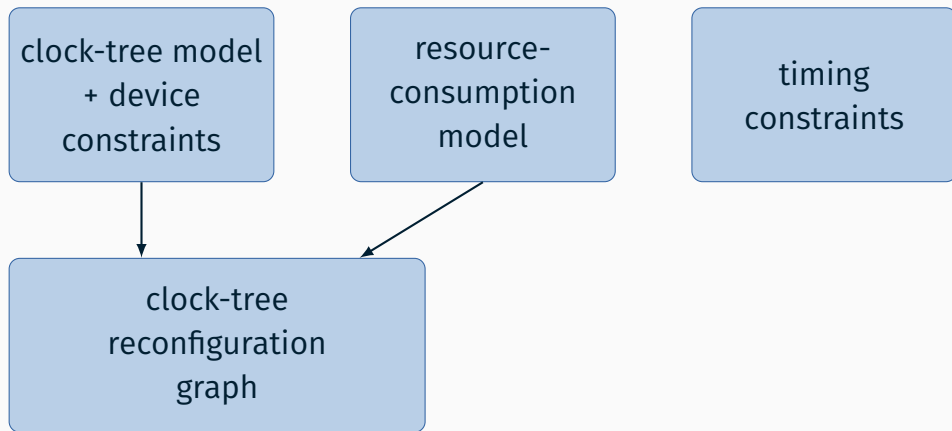
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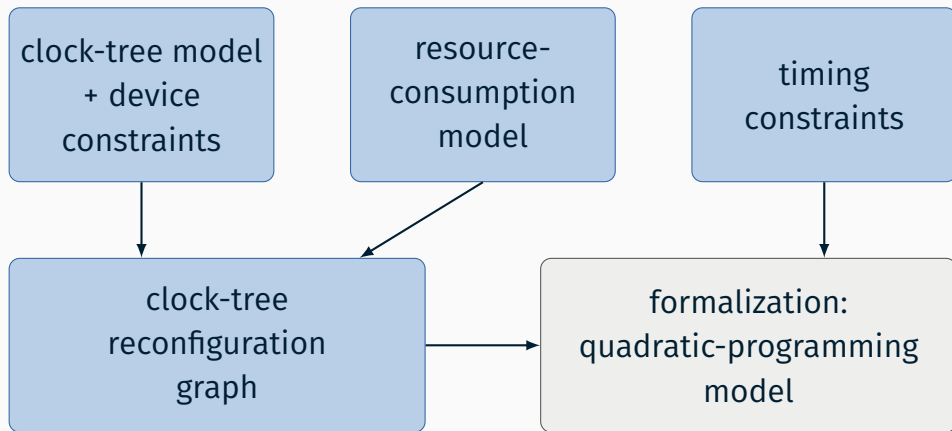
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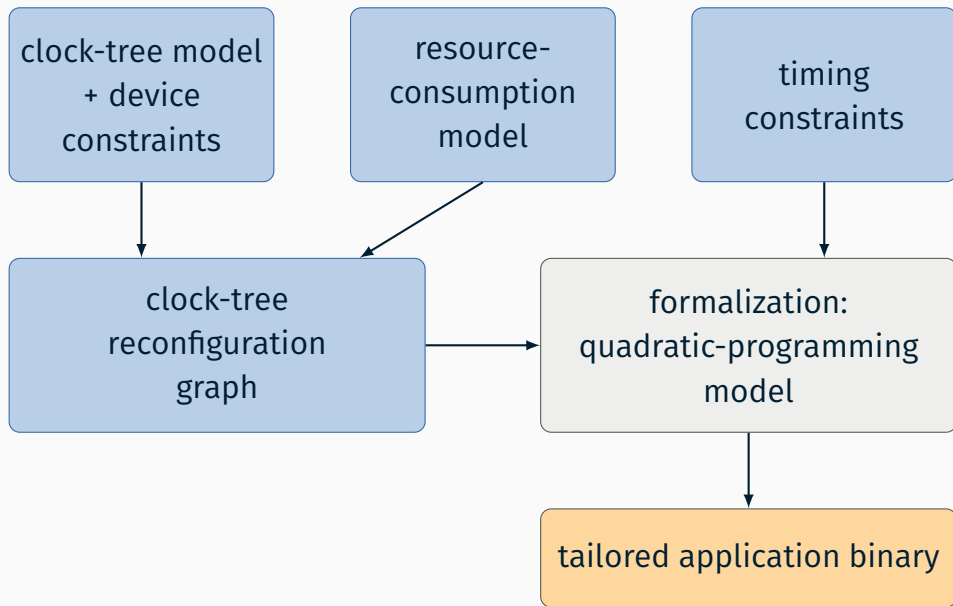
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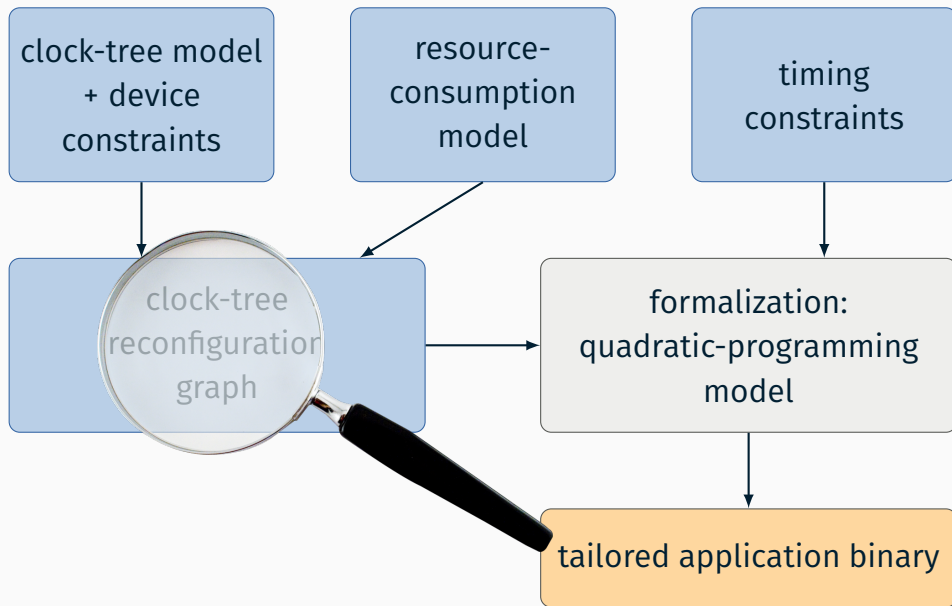
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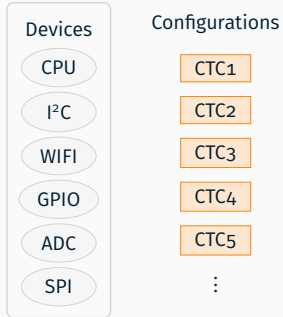
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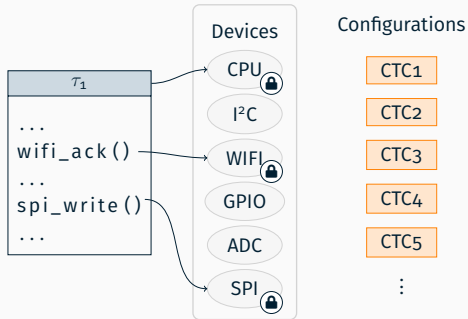
Clock-Tree Reconfiguration Graph



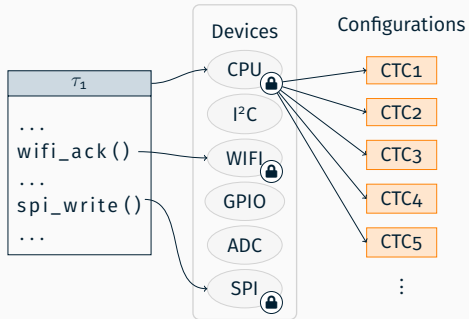
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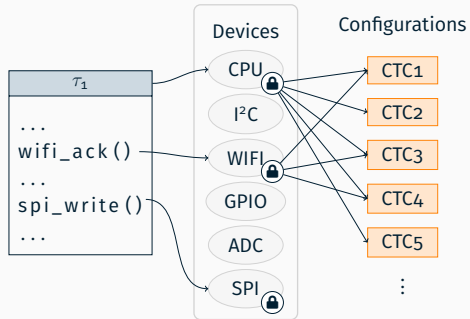
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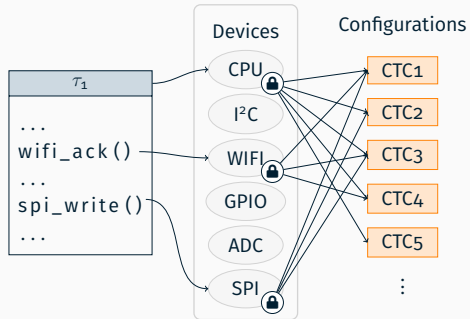
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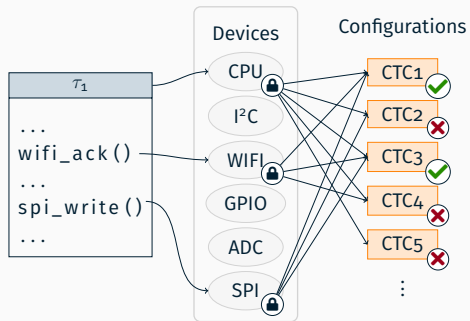
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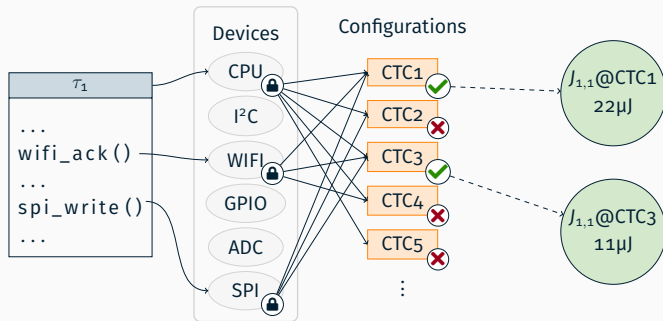
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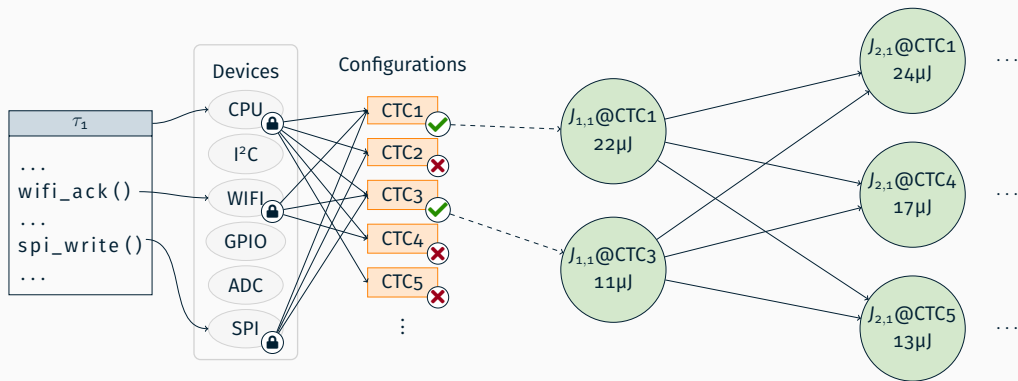
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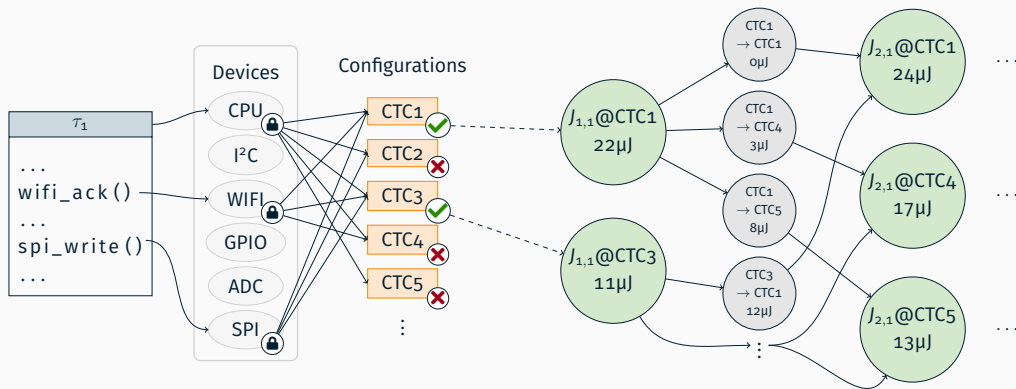
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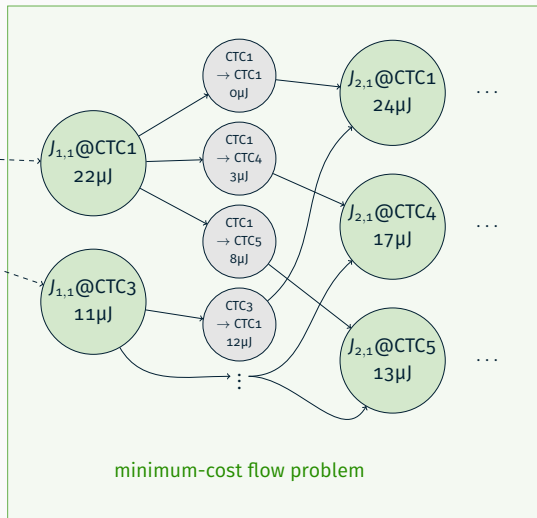
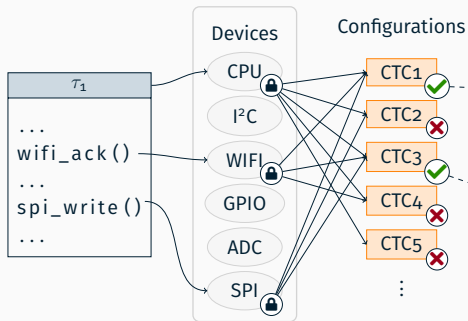
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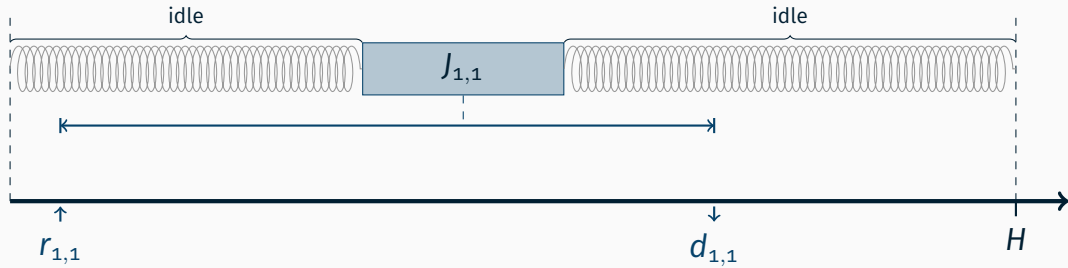
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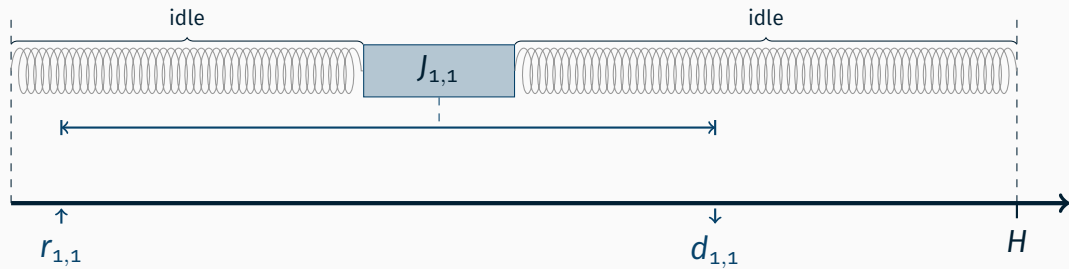
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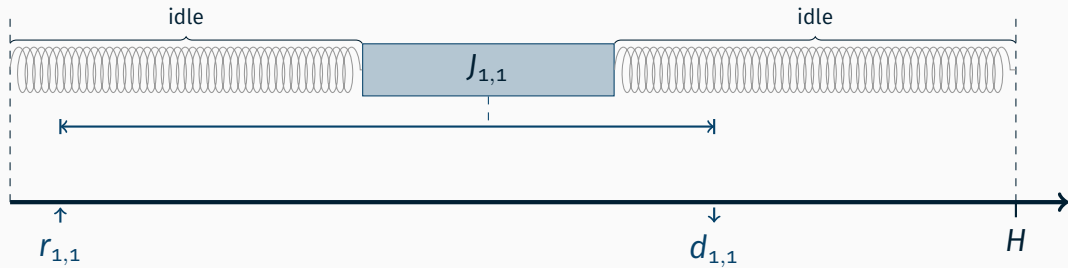
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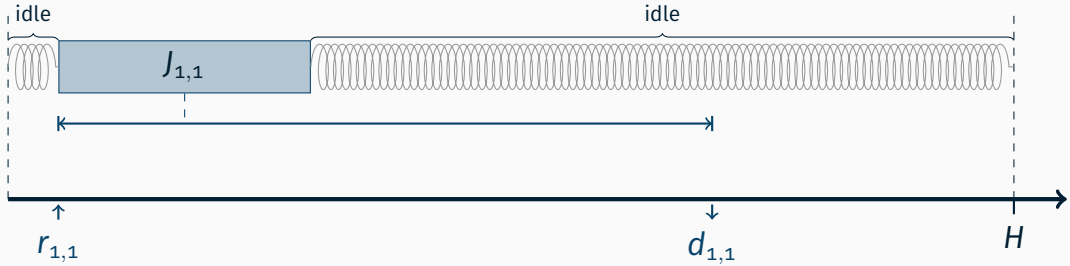
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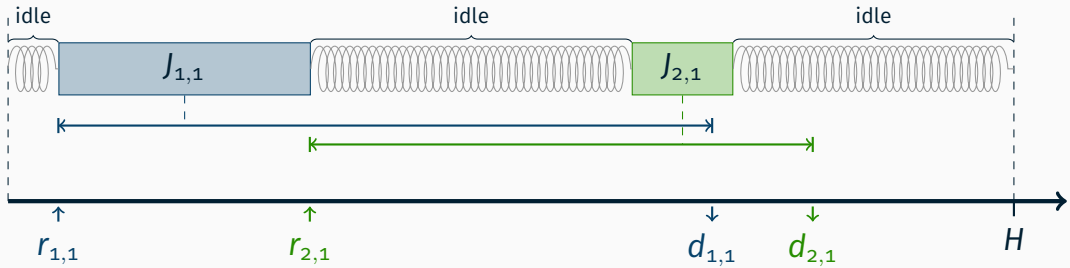
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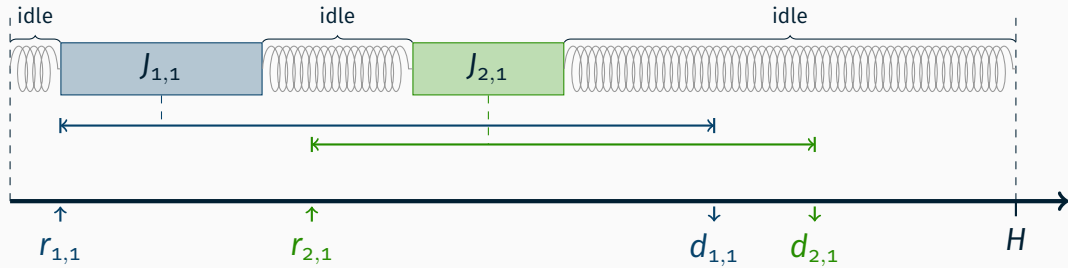
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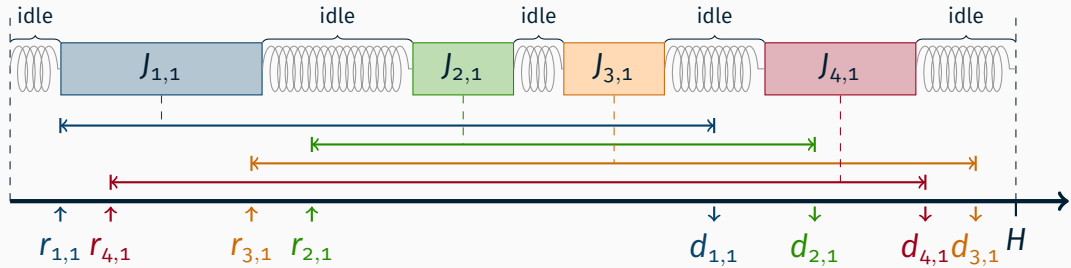
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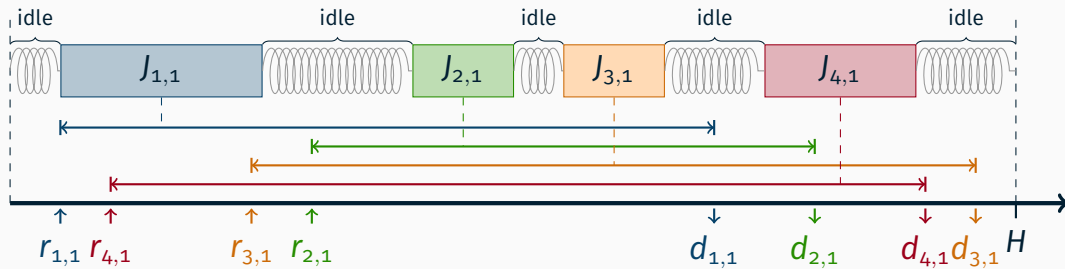
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Distributing the slack:

- **reconfiguration penalties**
- **idling**: start times, durations, and configurations

Formalization

min **energy costs** of jobs and idling options
+ **energy penalty** for reconfiguration

w.r.t.

constraints in the **clock-tree reconfiguration graph**

all times **sum up** to **hyperperiod**

each job **starts** at or after its **release time**

each job **finishes** before or at its **deadline**

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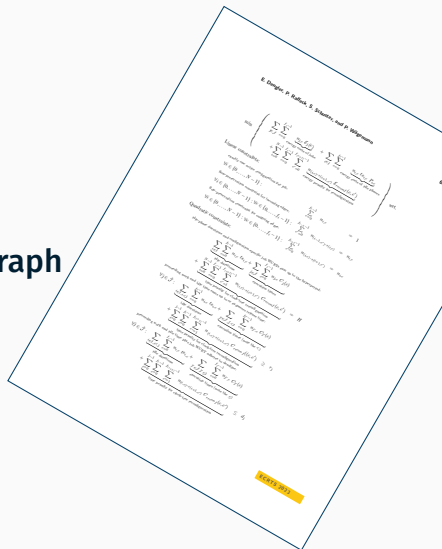
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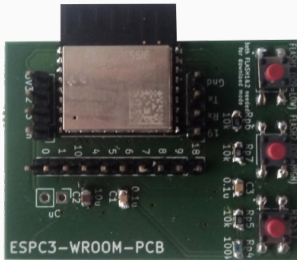
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Evaluation

Evaluation Hardware



Evaluation: Break-Even Point Analysis

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while(true) {  
    fibonacci_calculation();  
    idle(until=hyperperiod.end);  
}
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Evaluation: Break-Even Point Analysis

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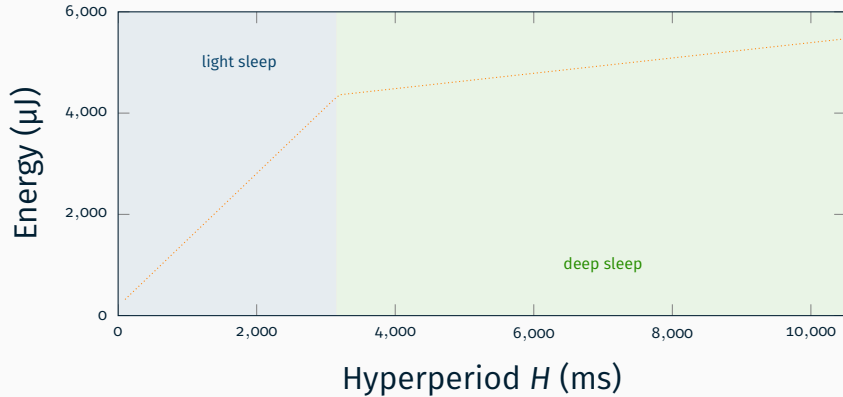
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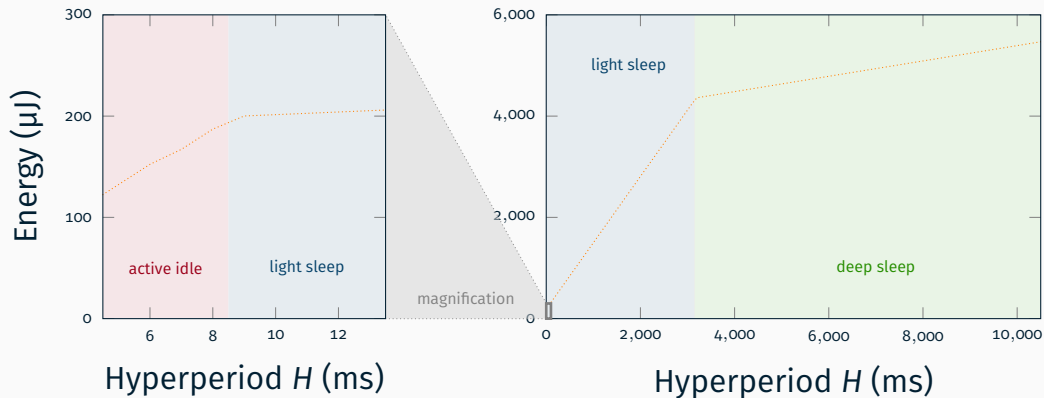
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- how do actual measurements compare to the predicted energy consumptions?

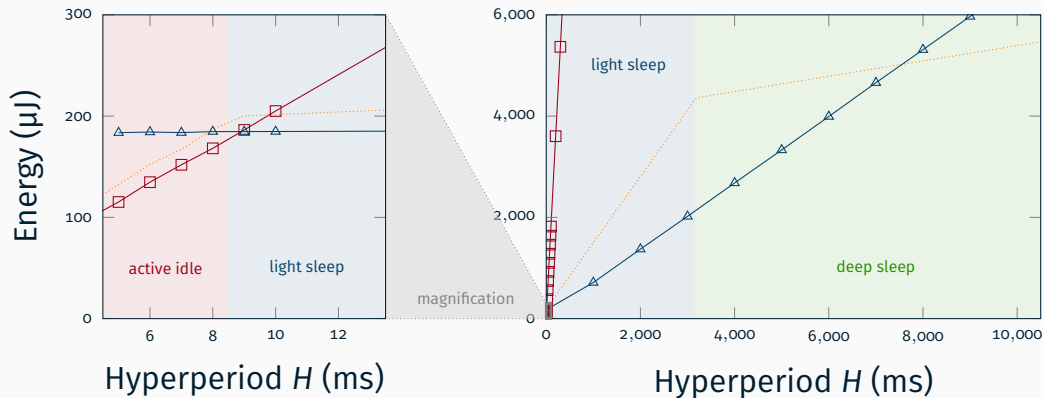
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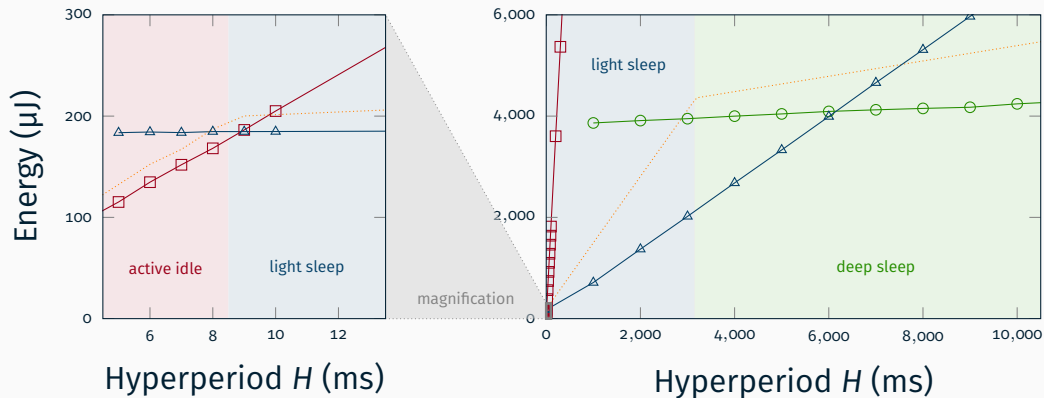
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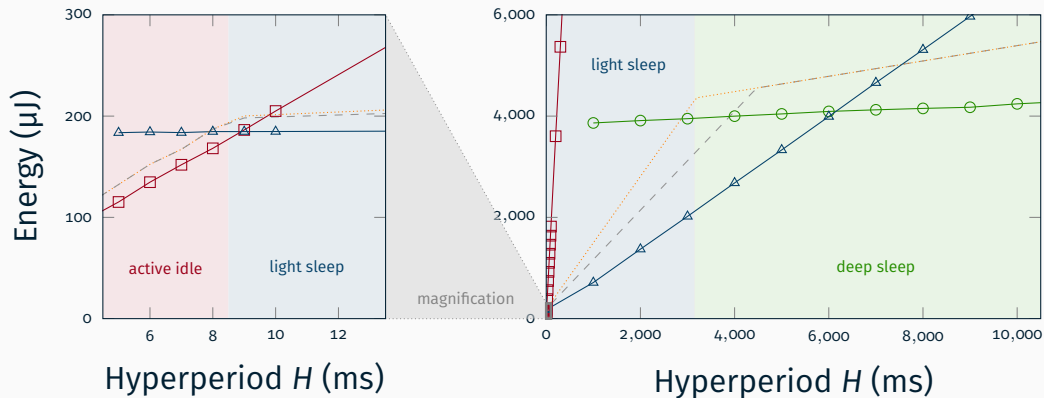
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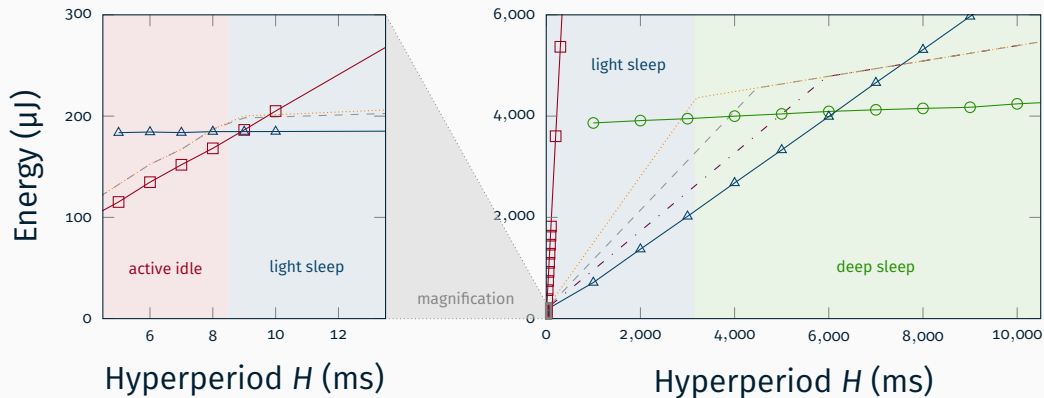
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Evaluation: Taskset Generation

Does FUSIONCLOCK ...

- ... determine a reliable upper bound?
- ... minimize energy consumption in comparison to device-unselective approaches?

Evaluation: Taskset Generation

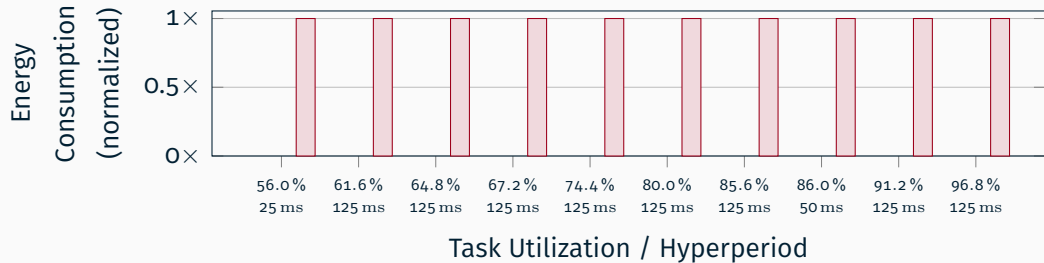
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Evaluation with generated tasksets:

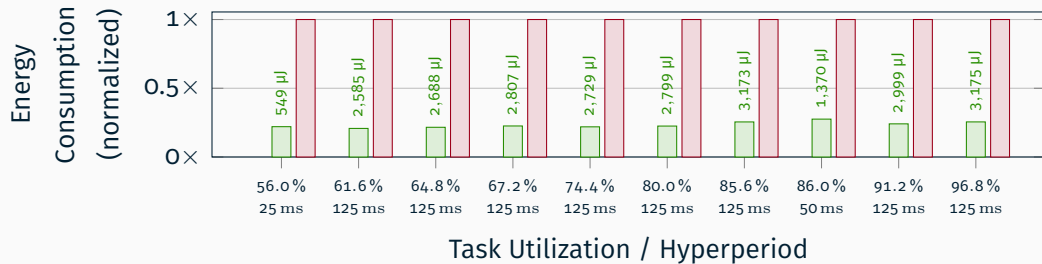
- simulate device usage: sense, compute, actuate
- 5 active modes
- 2 idle modes: light sleep, deep sleep
- 9 to 18 tasks

Evaluation: Taskset Generation



binary without clock-tree reconfigurations

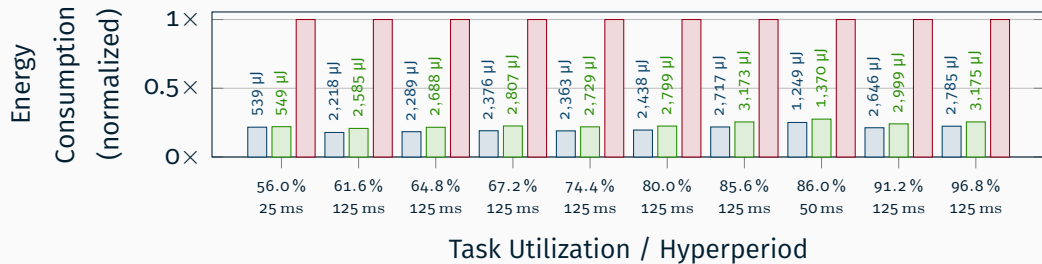
Evaluation: Taskset Generation



predicted energy consumption

binary without clock-tree reconfigurations

Evaluation: Taskset Generation

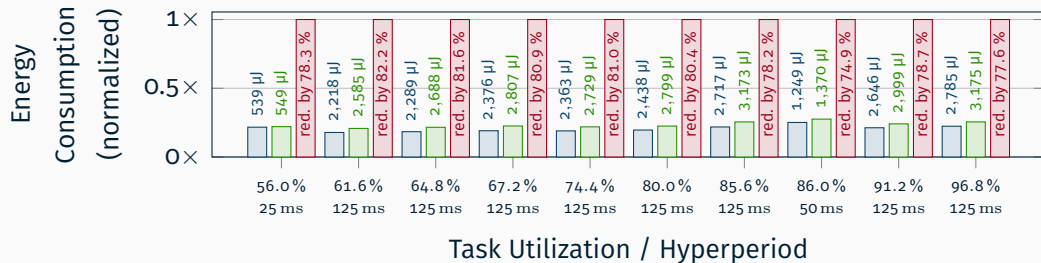


tailored application binary

predicted energy consumption

binary without clock-tree reconfigurations

Evaluation: Taskset Generation



tailored application binary

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Problems solved by FUSIONCLOCK

1. CPU-only approaches...
 - neglect energy consumption of devices
 - ignore dependencies of devices and clock-tree configurations
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 - ✓ **device-aware model, making use of the system's clock tree**
2. no guarantees of feedback-based approaches
 - ✓ **resource consumption guarantees due to static approach**
3. missing reconfiguration penalties
 - ✓ **inclusion of clock-tree reconfiguration costs in optimization**

Questions?

Source Code and Artifact Evaluation of FUSIONCLOCK

<https://gitlab.cs.fau.de/fusionclock>



E. Dengler, P. Raffeck, S. Schuster, and P. Wägemann.

**FusionClock: WCEC-Optimal Clock-Tree
Reconfigurations (Artifact).**

Dagstuhl Artifacts Series, 9(1):2:1–2:3, 2023.

