usenix nsdi’21

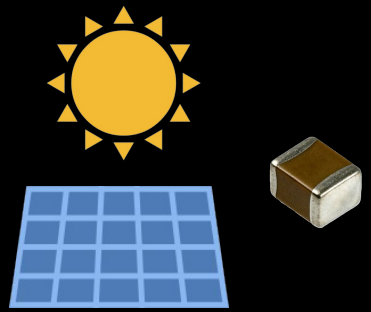
Bootstrapping Battery-free Wireless Networks

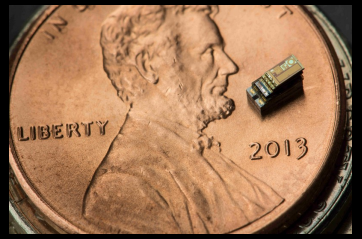
Efficient Neighbor Discovery and Synchronization in the Face of Intermittency

Kai Geissdoerfer and Marco Zimmerling

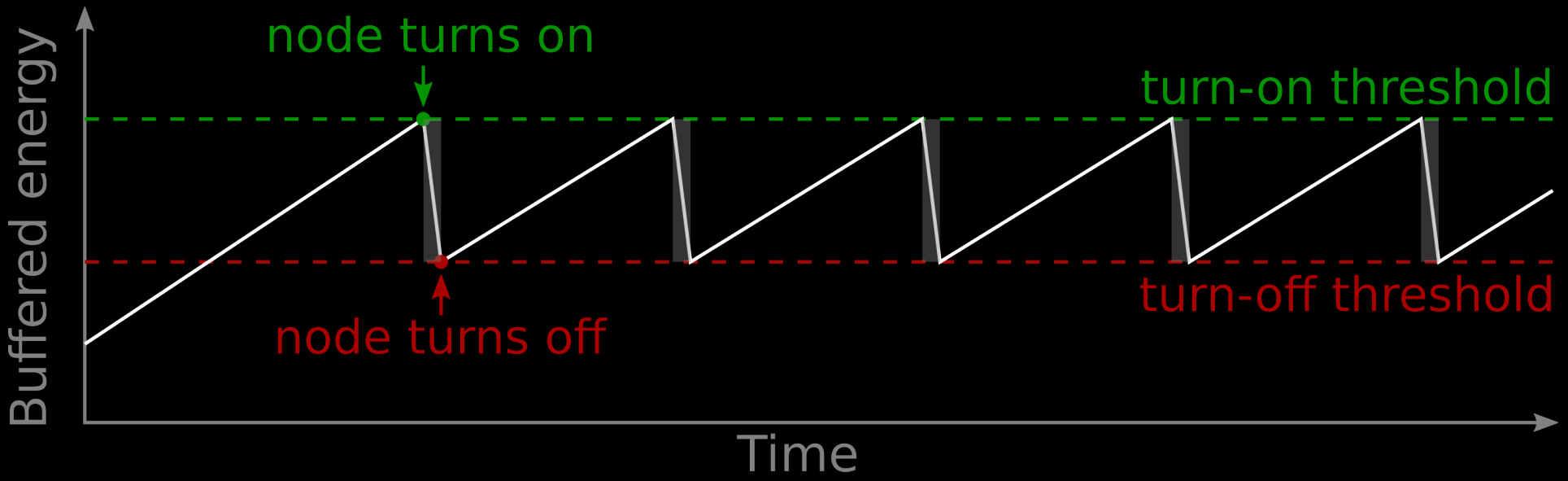
TECHNISCHE UNIVERSITÄT DRESDEN

Going Battery-free





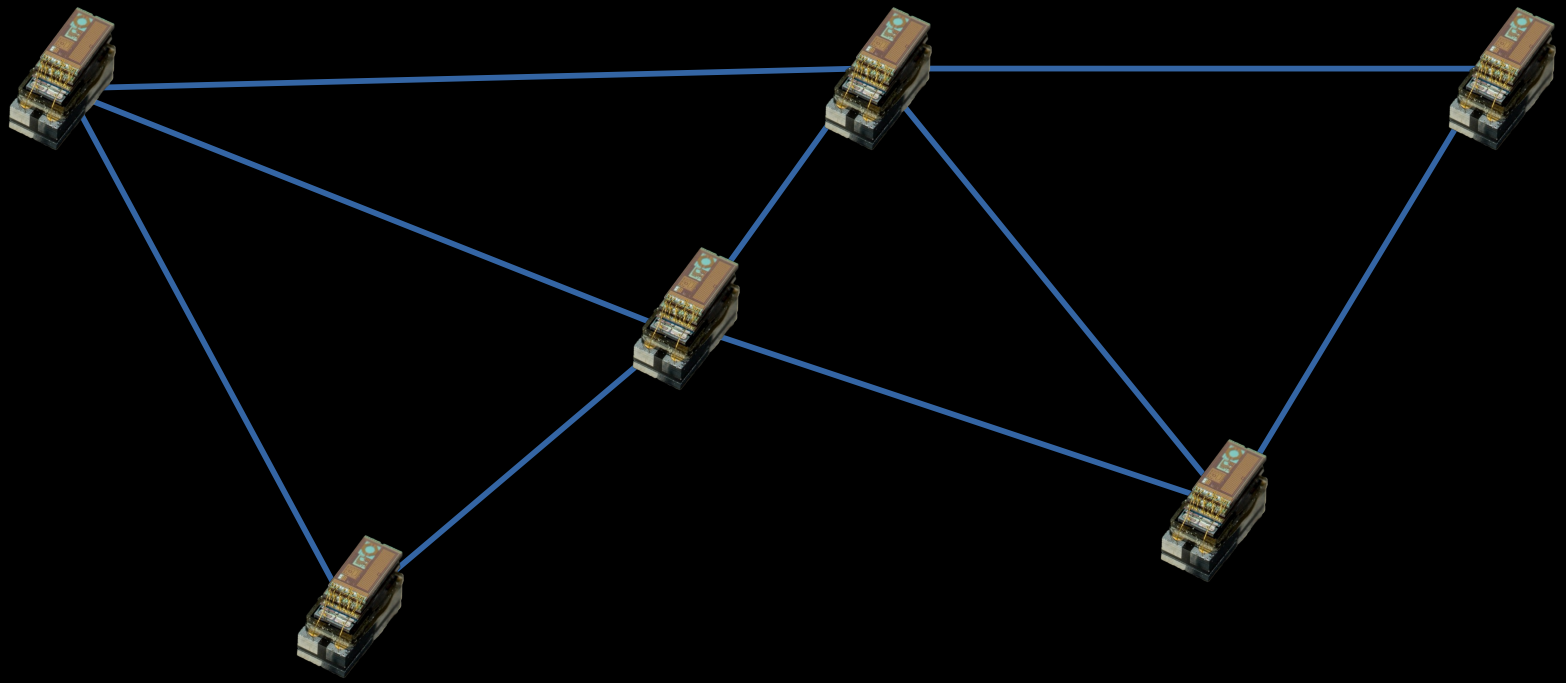
Intermittent Operation



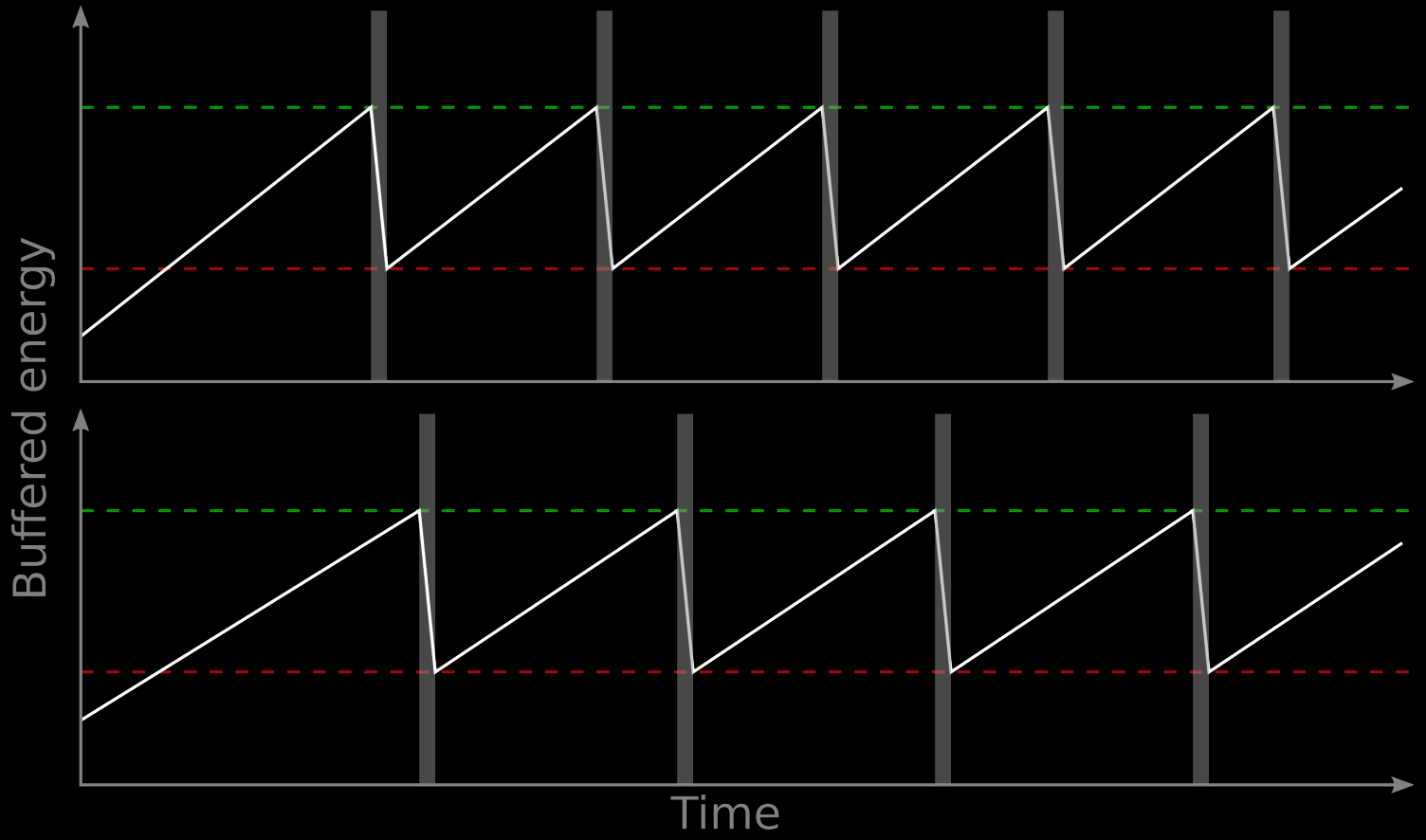
Intermittent Computing

- Focus on individual devices:
  - Forward progress Maeng OSDI ‘18
  - Time-keeping DeWinkel ASPLOS ‘20

Battery-free Networks



Interleaving

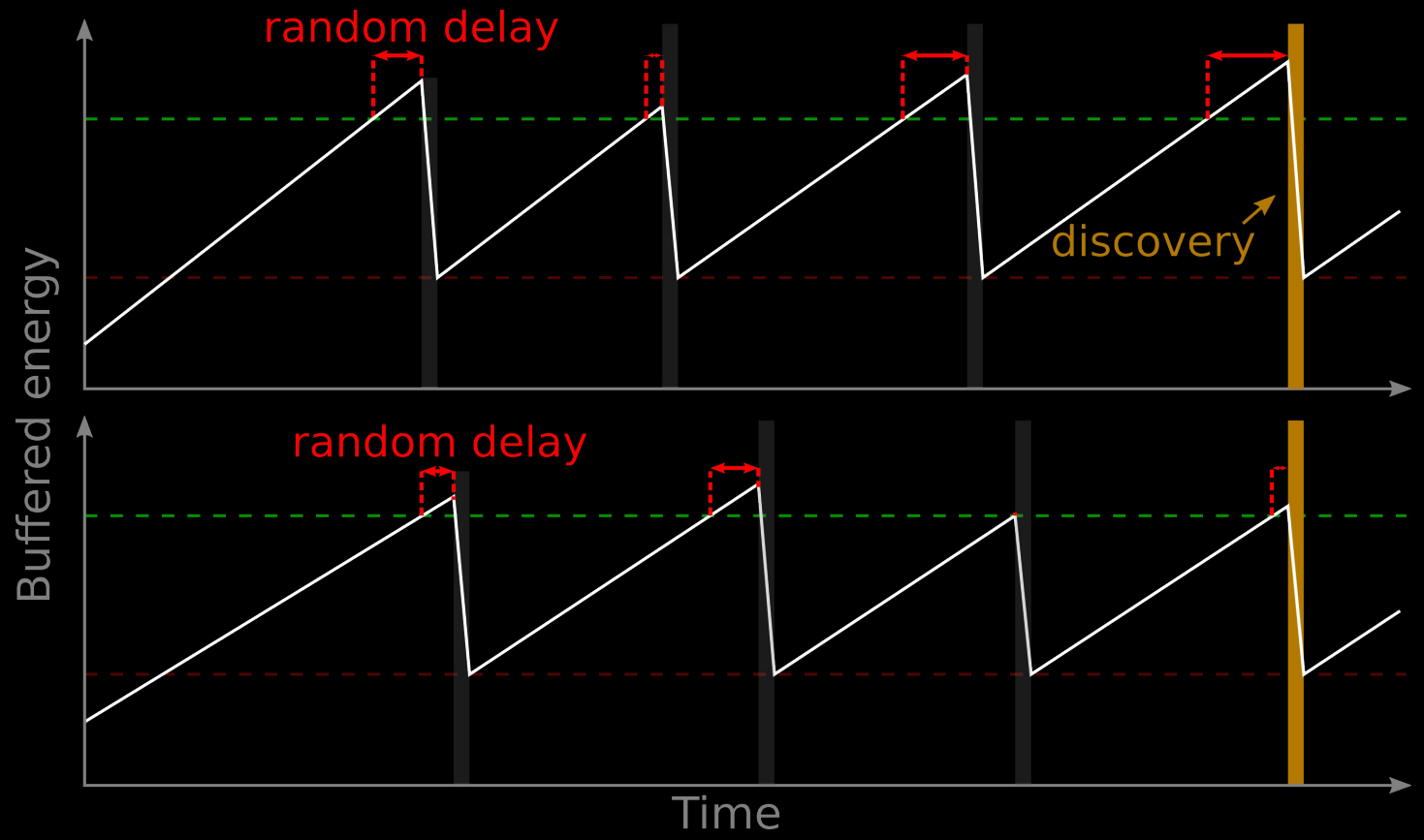


Our Contribution

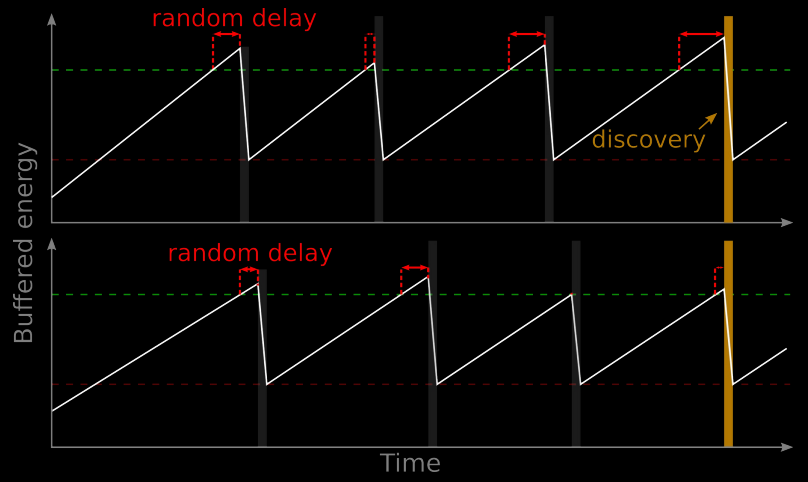
FIND: breaks the interleaving pattern by introducing random wake-up delays

FLYNC: aligns wake-ups of nodes to a common synchronization signal

FIND



FIND

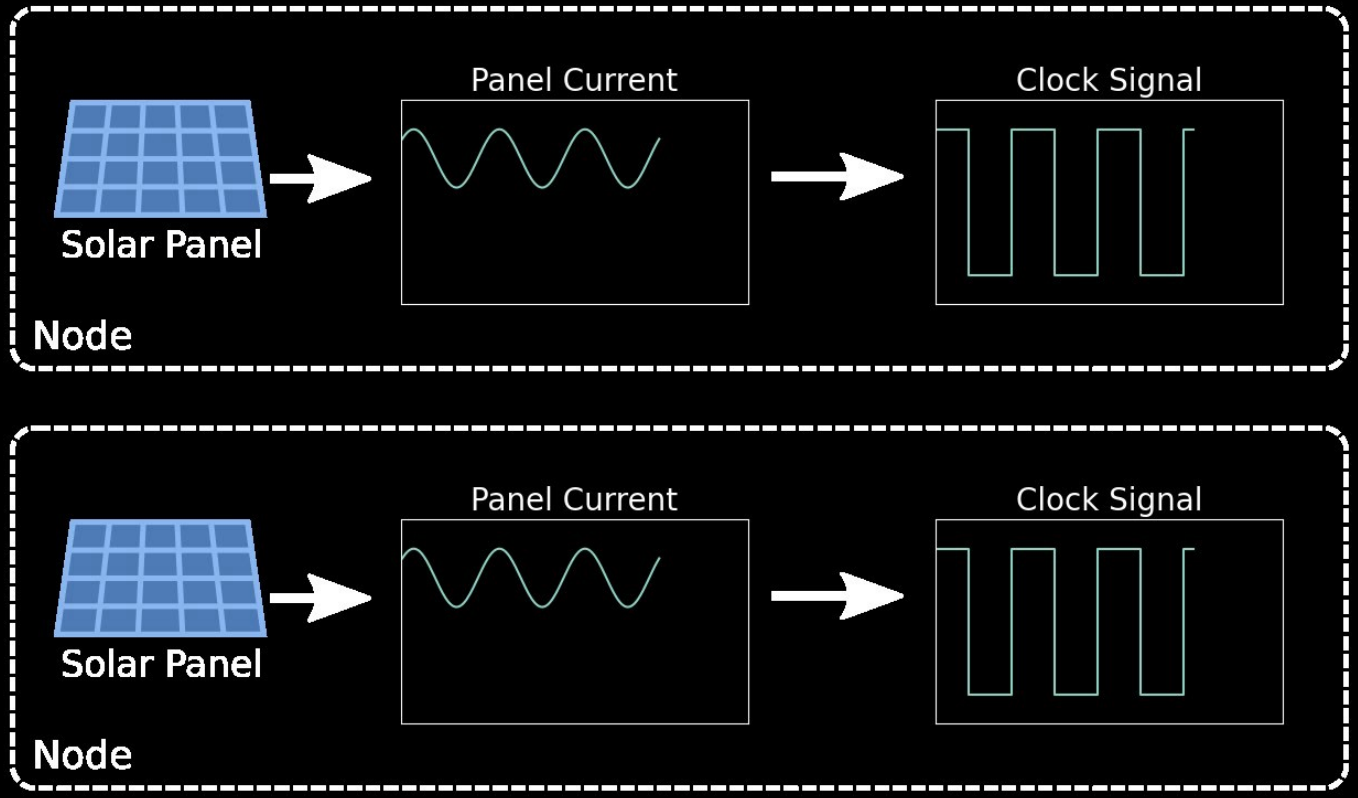


- Random wake-up delays speed up discovery
- Geometrically distributed wake-up delays perform well
- Nodes adapt distribution to changes in energy availability

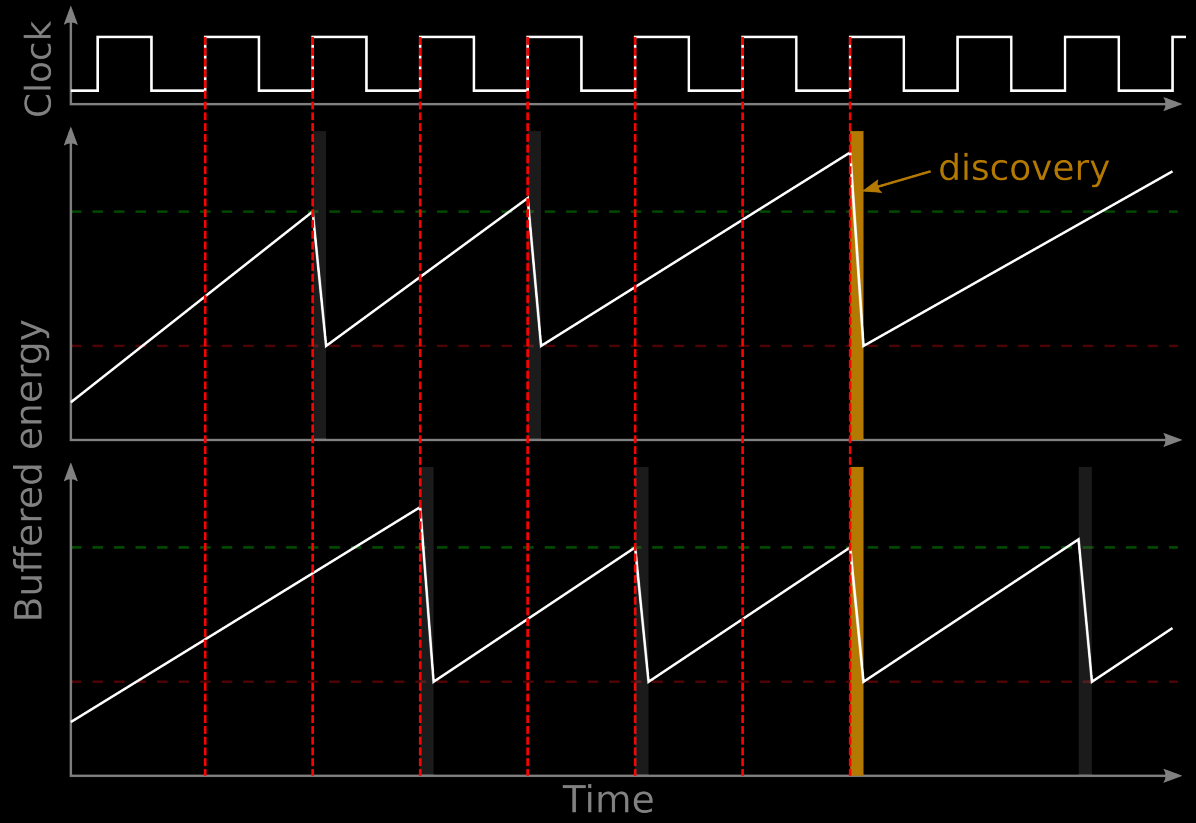
Our Contribution

FIND: breaks the interleaving pattern by introducing random wake-up delays

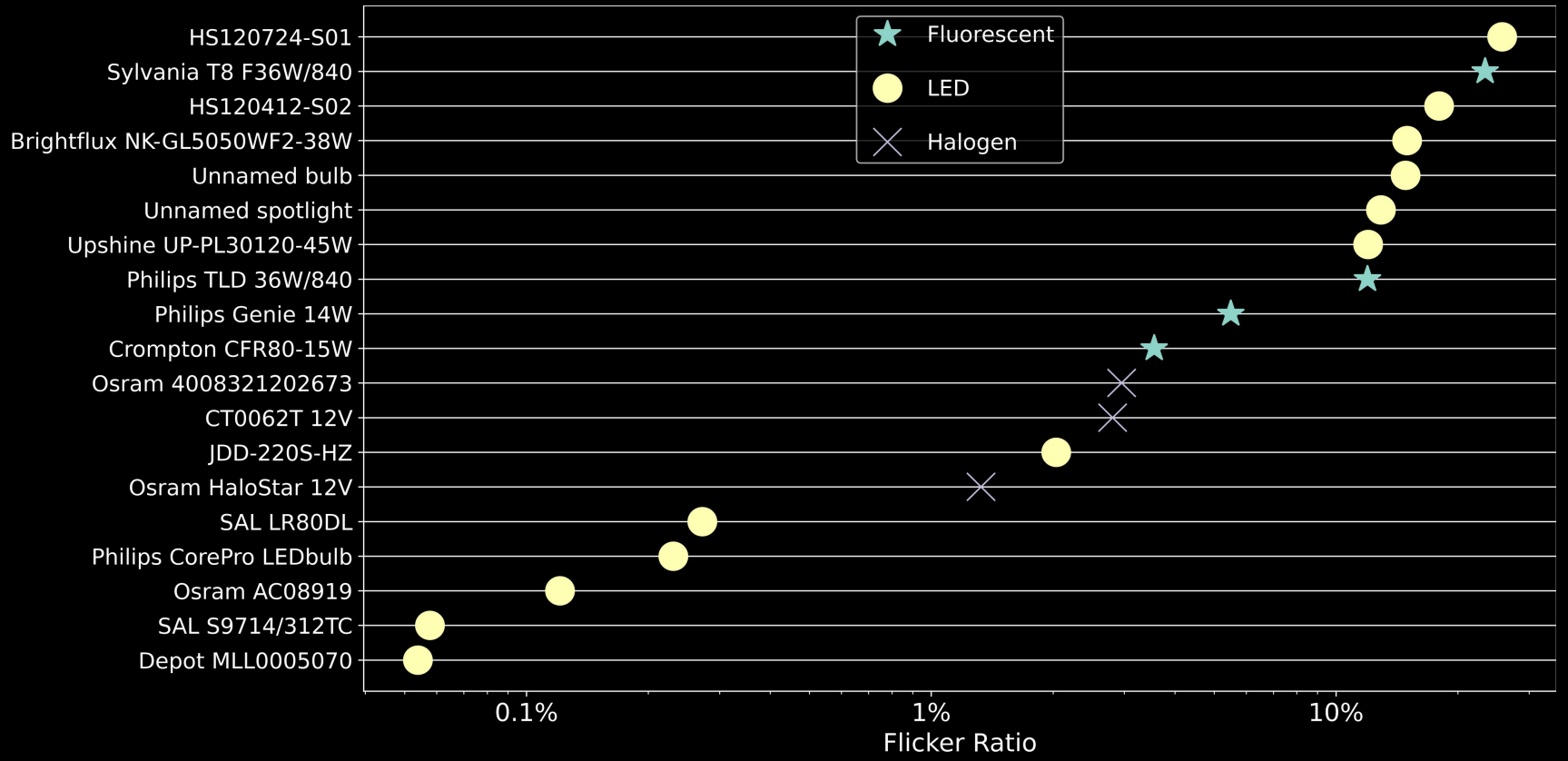
FLYNC: aligns wake-ups of nodes to a common synchronization signal


Panel Current
Clock Signal
Solar Panel
Node
Panel Current
Clock Signal
Solar Panel
Node

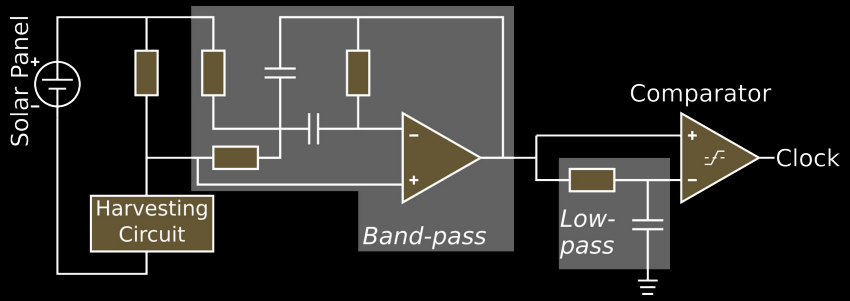
FLYNC



Flicker

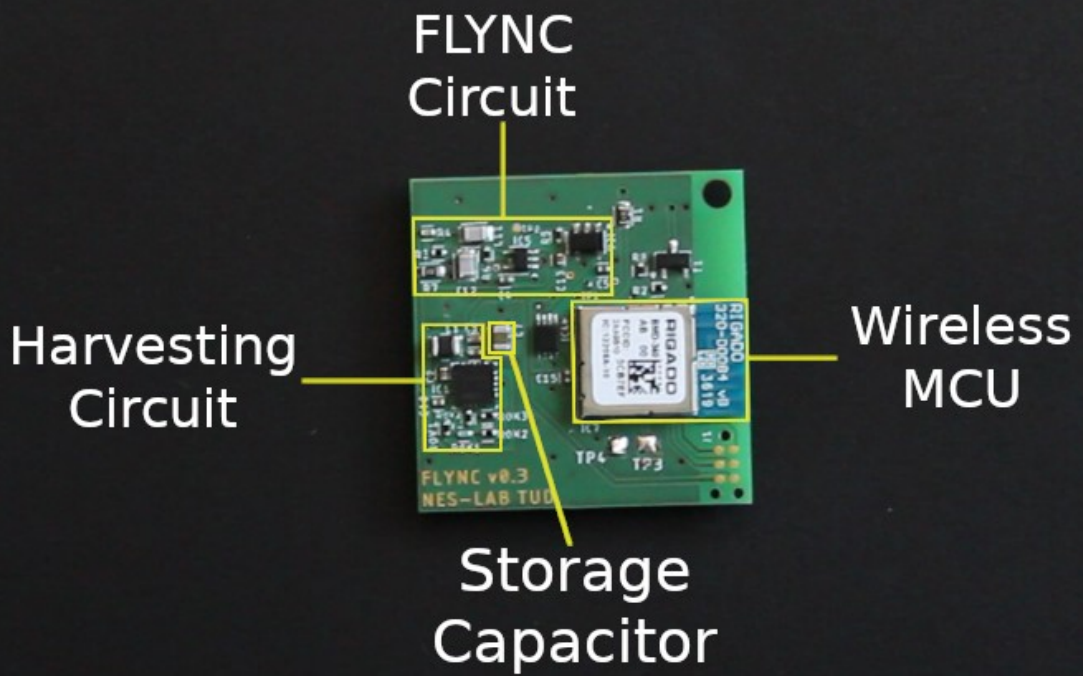

HS120724-S01
Sylvania T8 F36W/840
HS120412-S02
Brightflux NK-GL5050WF2-38W
Unnamed bulb
Unnamed spotlight
Upshine UP-PL30120-45W
Philips TLD 36W/840
Philips Genie 14W
Crompton CFR80-15W
Osram 4008321202673
CT0062T 12V
JDD-220S-HZ
Osram HaloStar 12V
SAL LR80DL
Philips CorePro LEDbulb
Osram AC08919
SAL S9714/312TC
Depot MLL0005070
Fluorescent
LED
Halogen
0.1%
1%
10%
Flicker Ratio

FLYNC Circuit

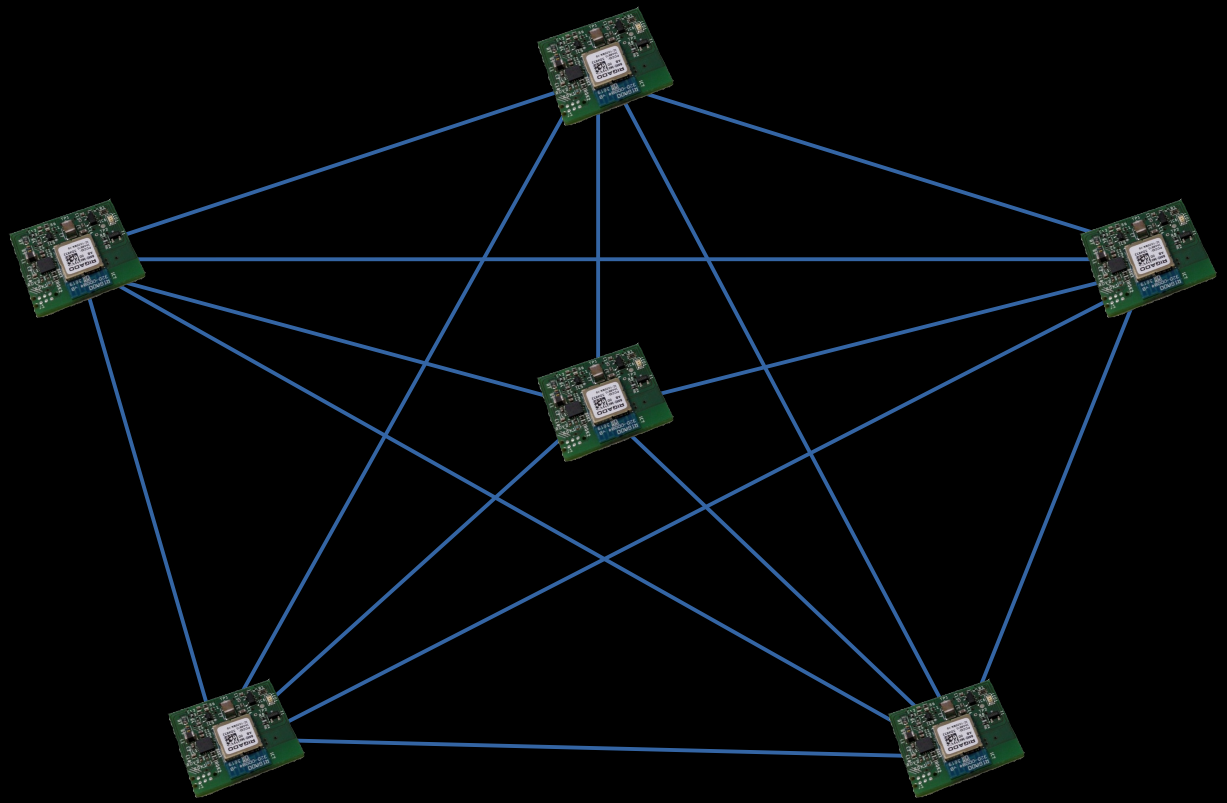


< 5uW power consumption

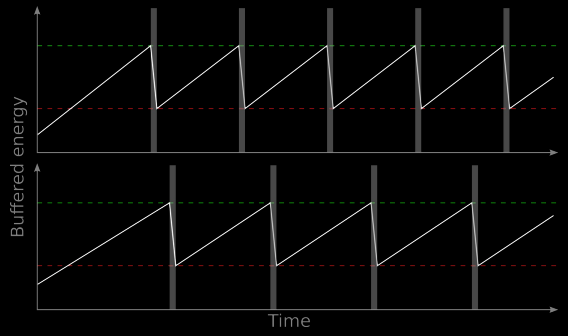
- ✓ 14 out of 19 tested lamps
- ✓ different rooms
- ✓ partial sunlight
- ⊗ lamps with different phase offsets


FLYNC
Circuit
Harvesting
Circuit
Wireless
MCU
Storage
Capacitor
FLYNC v0.3
NES-LAB TU
TP4
TP3

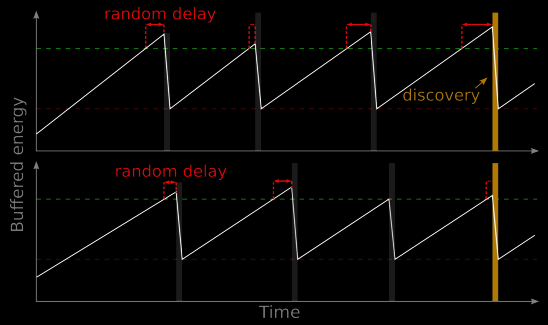
Neighbor Discovery Performance



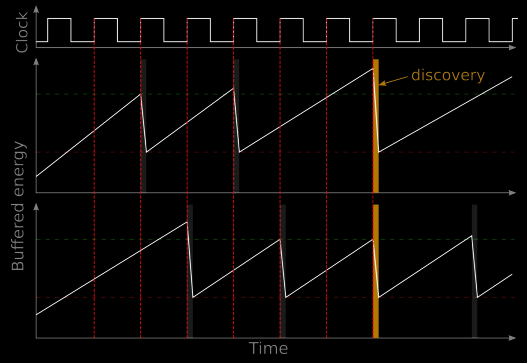
Neighbor Discovery Performance



Greedy



FIND



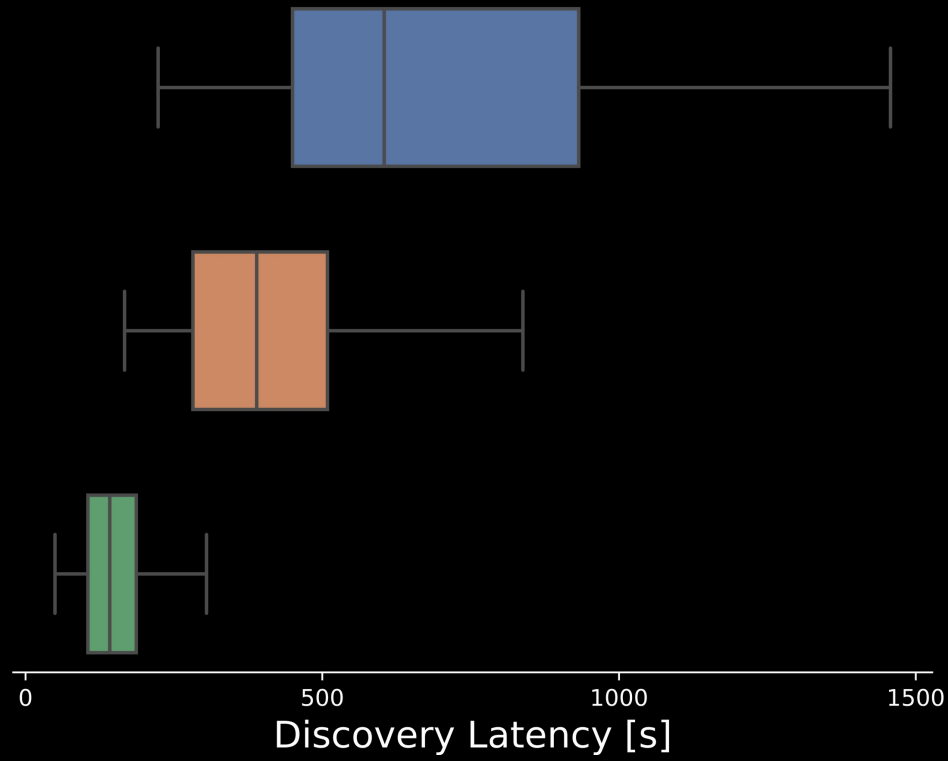
FIND and FLYNC

Neighbor Discovery Performance

Greedy

FIND

FIND and FLYNC



Improvement of 4.3x (median) and 34.4x (99th percentile)

Case Study: Contact Tracing

Case Study: Contact Tracing

Outdoors: Open-air cafeteria

2.67s link discovery latency

Indoors: Coffee kitchen

7.5s link discovery latency

Summary

- Device-to-device communication for intermittently powered systems
- Efficient synchronization for indoor light harvesting devices
- Open source
  - FIND model in Python
  - Hardware design
  - Firmware

https://find.nes-lab.org

kai.geissdoerfer@tu-dresden.de