Tragedy of the Coulombs

Federating Energy Storage for Tiny, Intermittently-Powered Sensors

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Sensing


CrossbowTelos


AAA
DURACELL
ALKALINE BATTERY
AAA
DURACELL
ALKALINE BATTERY

This Talk

1. Batteryless sensing challenges

2. Problems with centralized energy

3. Federating energy

Vision

Sophisticated sensing on batteryless devices

Batteryless Devices

UMass Moo

Batteryless Devices

Batteryless Devices

Batteryless Devices

UMass Moo

Batteryless Devices

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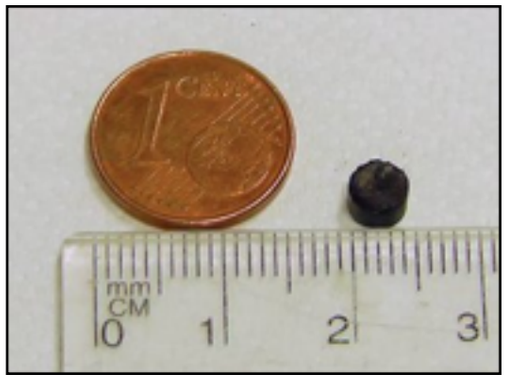
As small as possible

- Minimal energy storage (Cap)
- Harvest energy (RF, Solar, Glucose)



Run when you can

- Frequent failures
- Erratic supply

Applications

Infrastructure Monitoring

Pipelines
Bridges
Roads

Wildlife Tracking

Small animal
Implant once

Building Monitoring

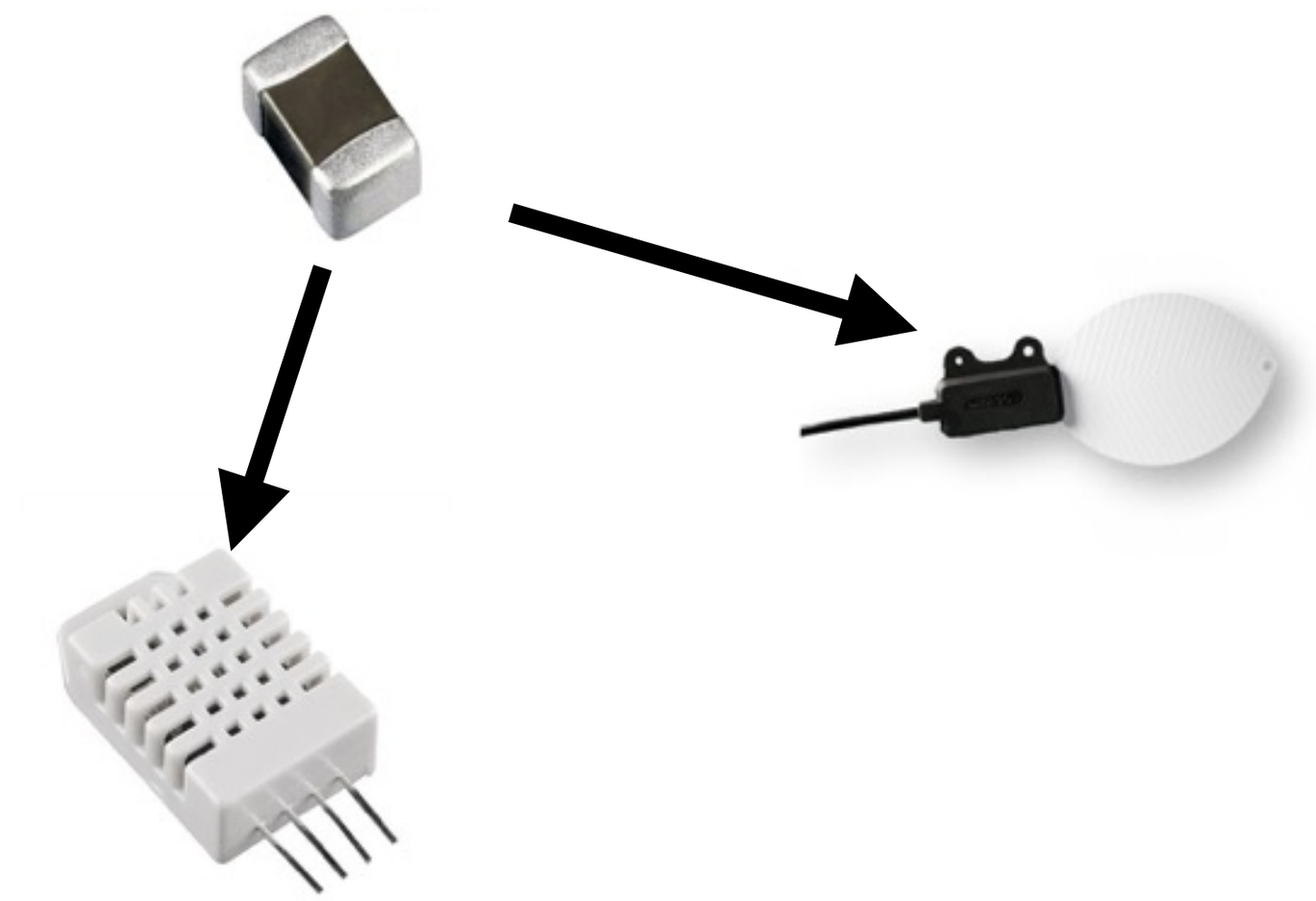
Occupancy
Energy Waste

Wearables

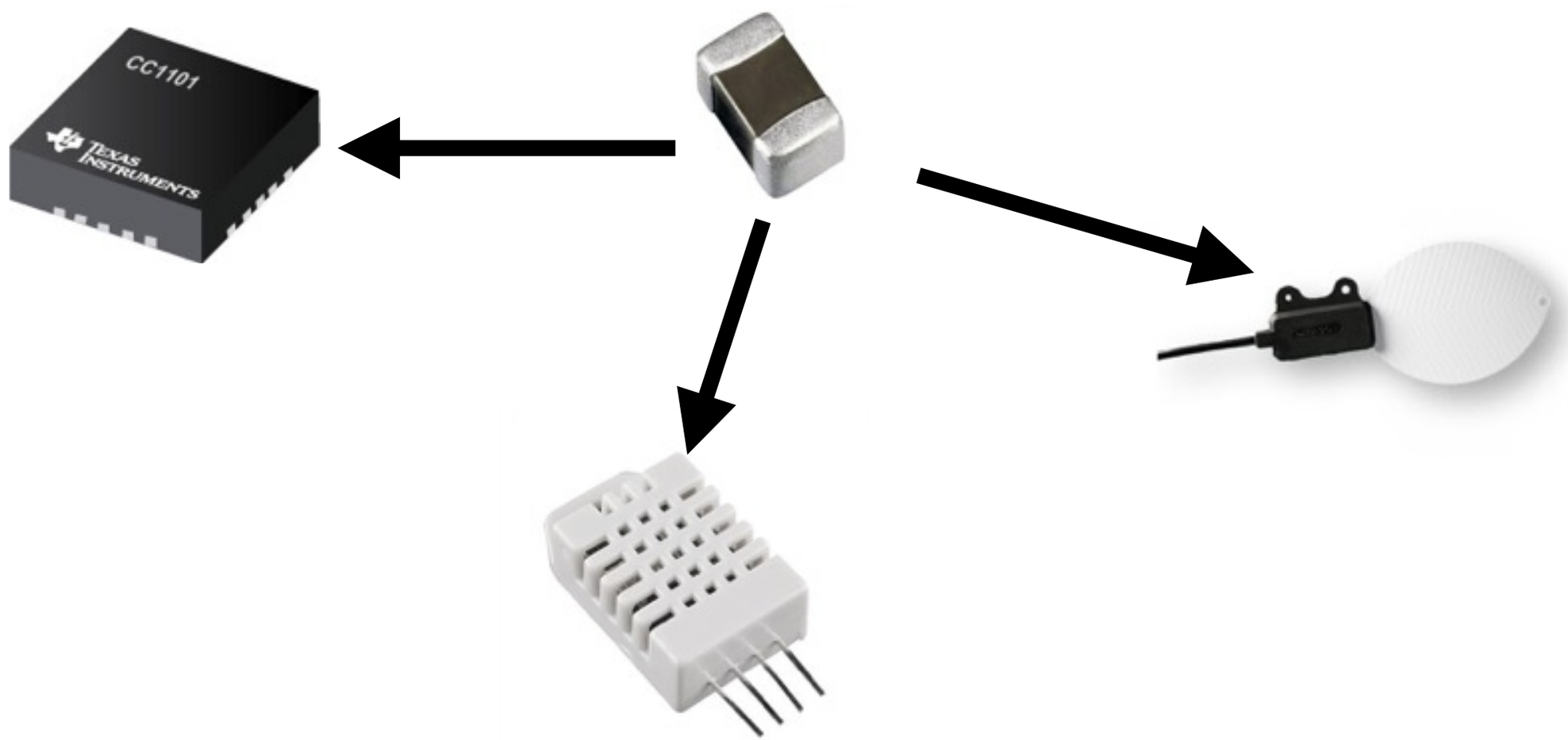
Clothing
Jewelry

Tragedy of the Commons

Tragedy of the Commons



Tragedy of the Commons



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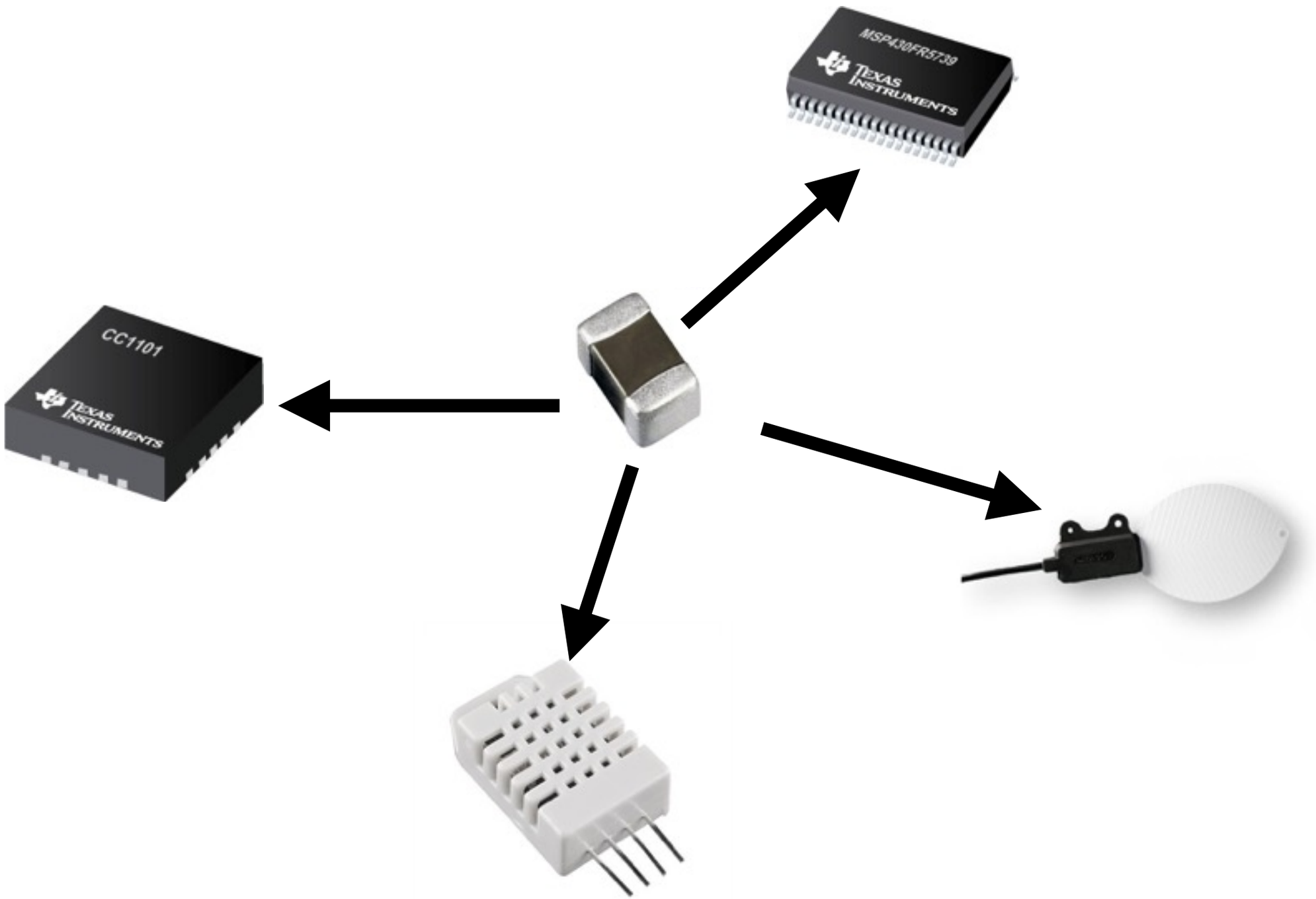


Greenhouse Monitoring

Water waste is a problem

- Overwatering typical
- Coarse data on plants

Dense sensing is a solution

- Fine grained plant information
- Cheap, non-invasive, long lived

Greenhouse Monitoring

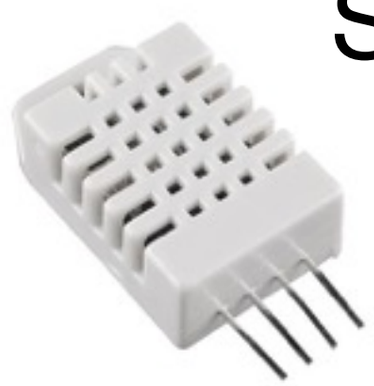
Radio

Computation

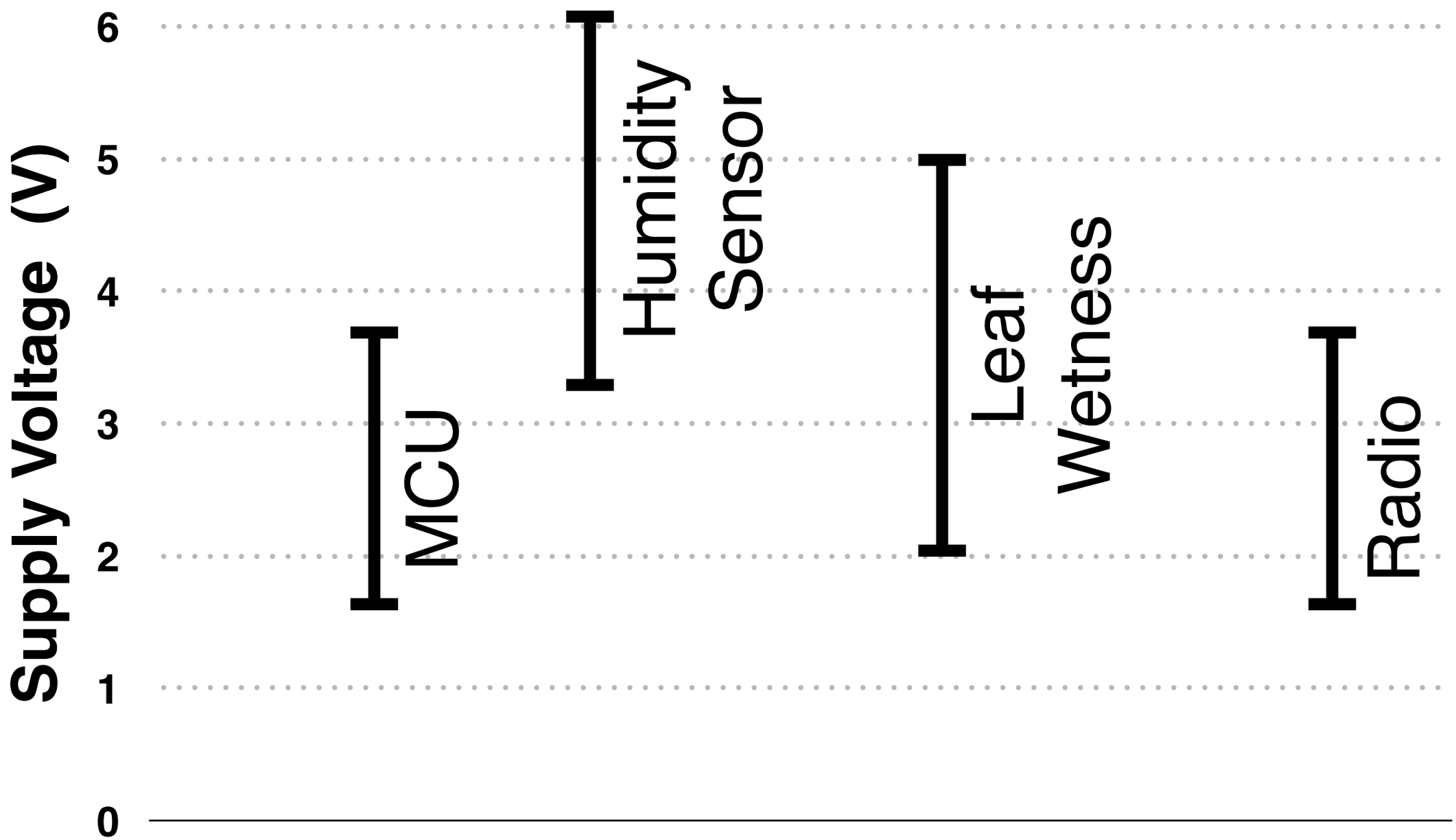
Harvesting

Storage

Sensing



Batteryless Sensing



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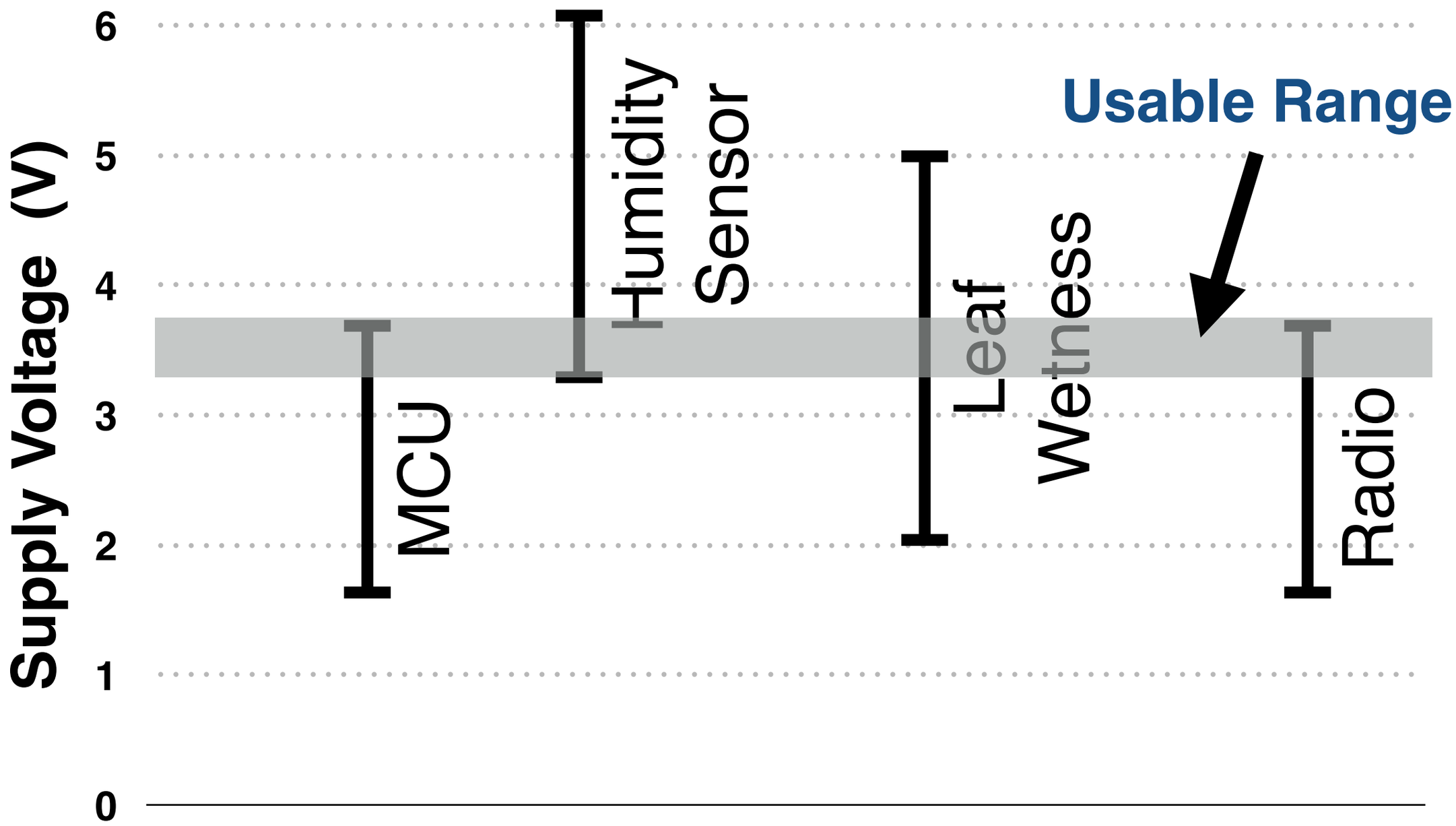

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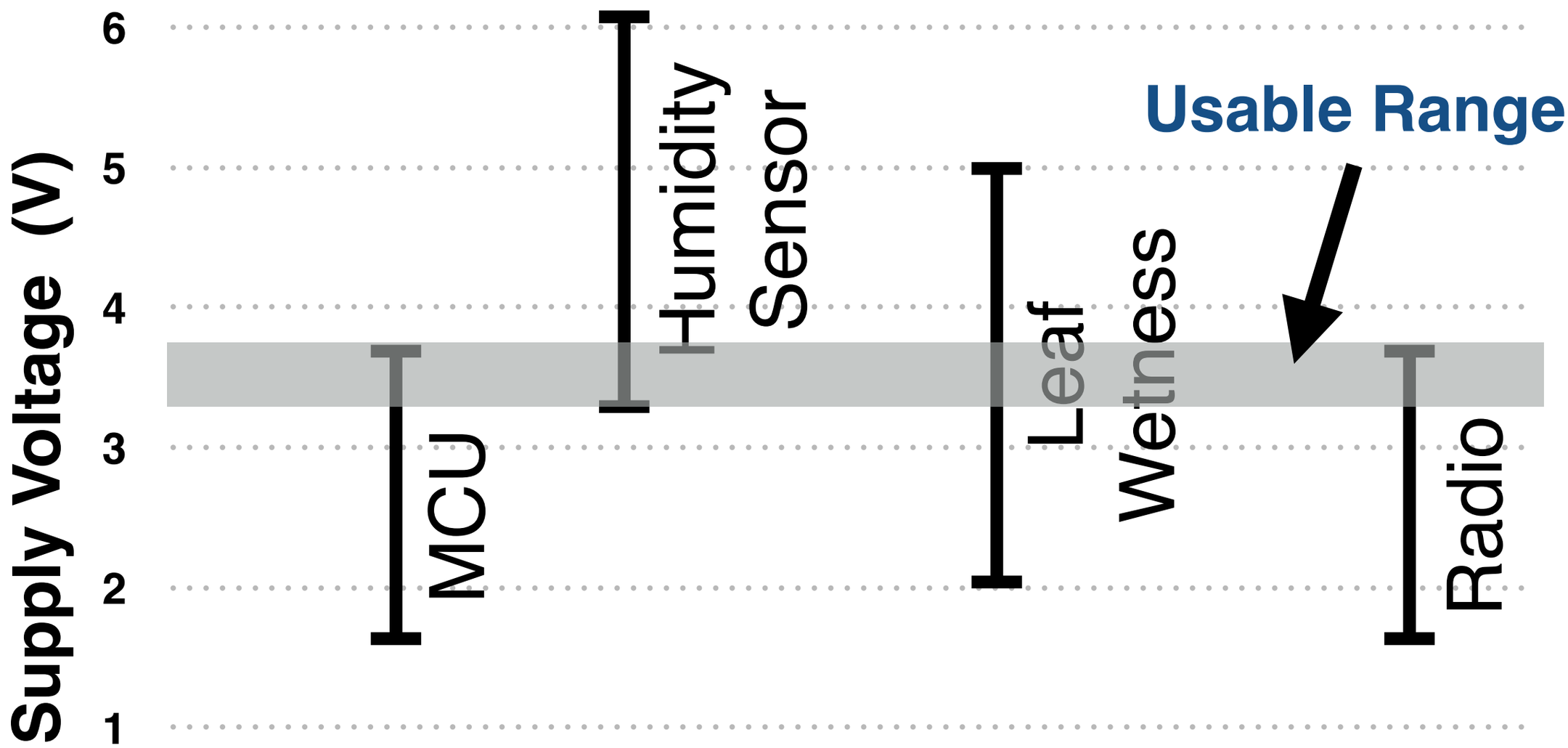
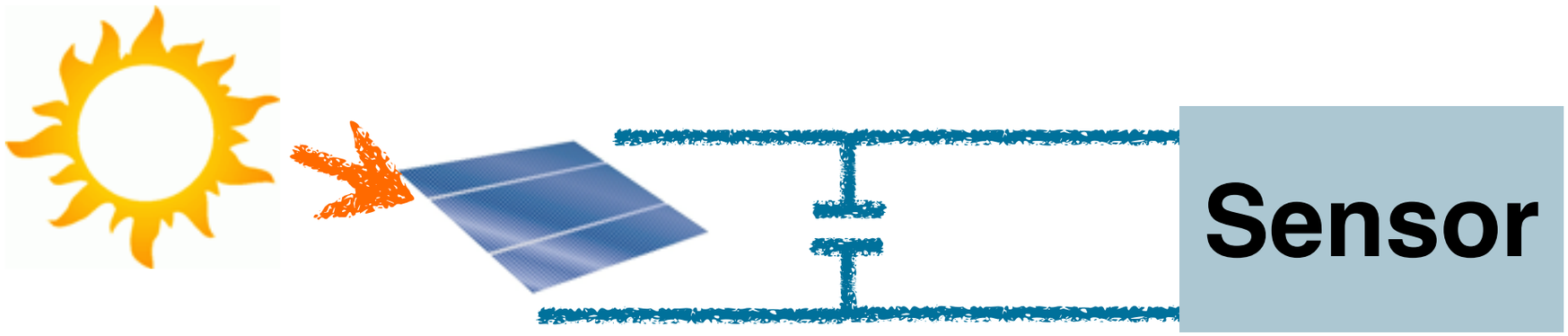
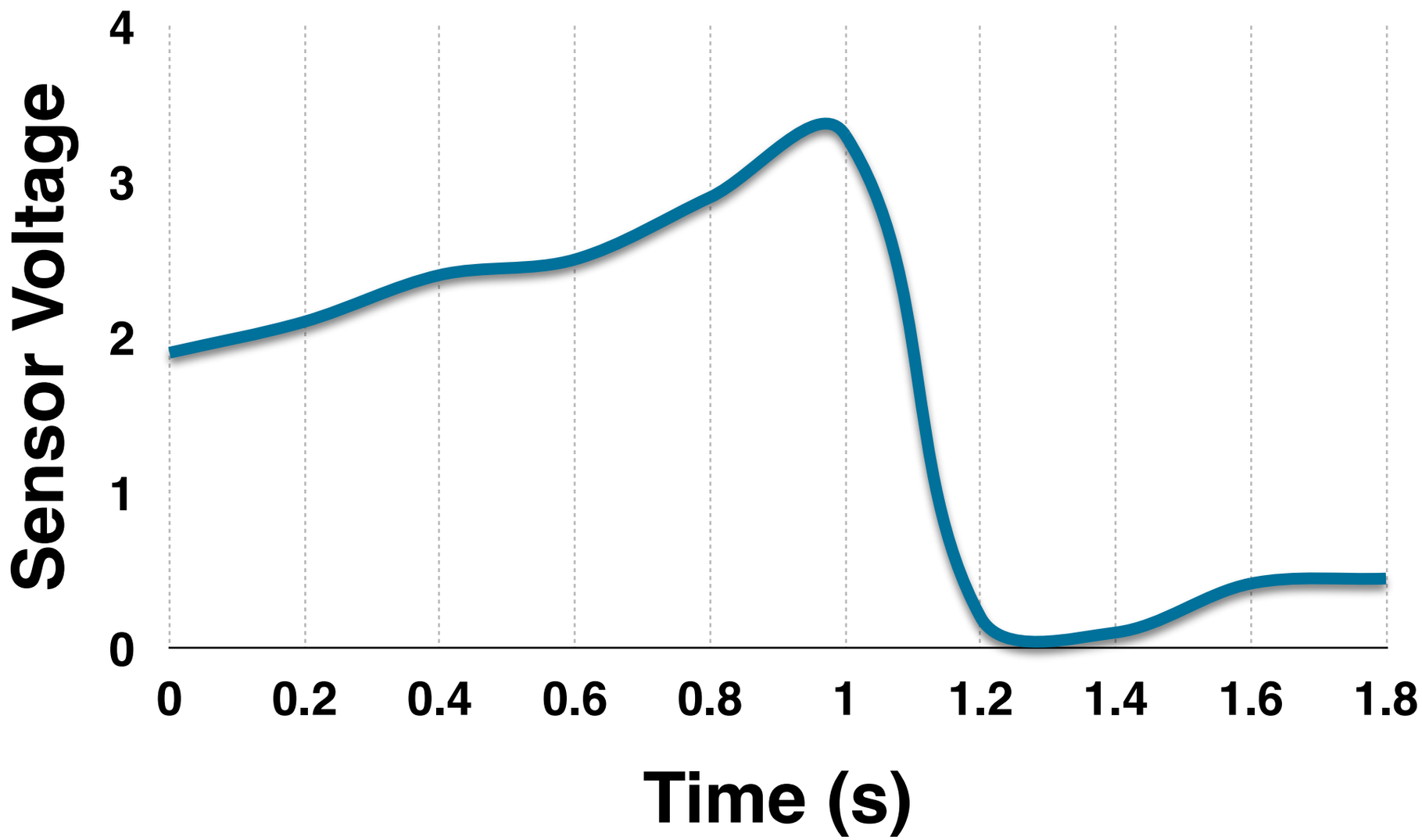


Voltage requirements vary

Batteryless Sensing





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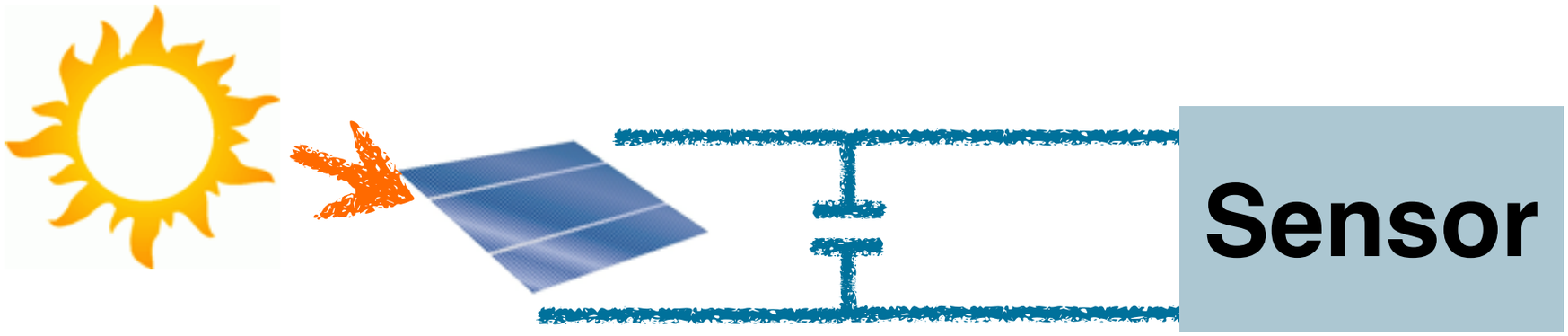

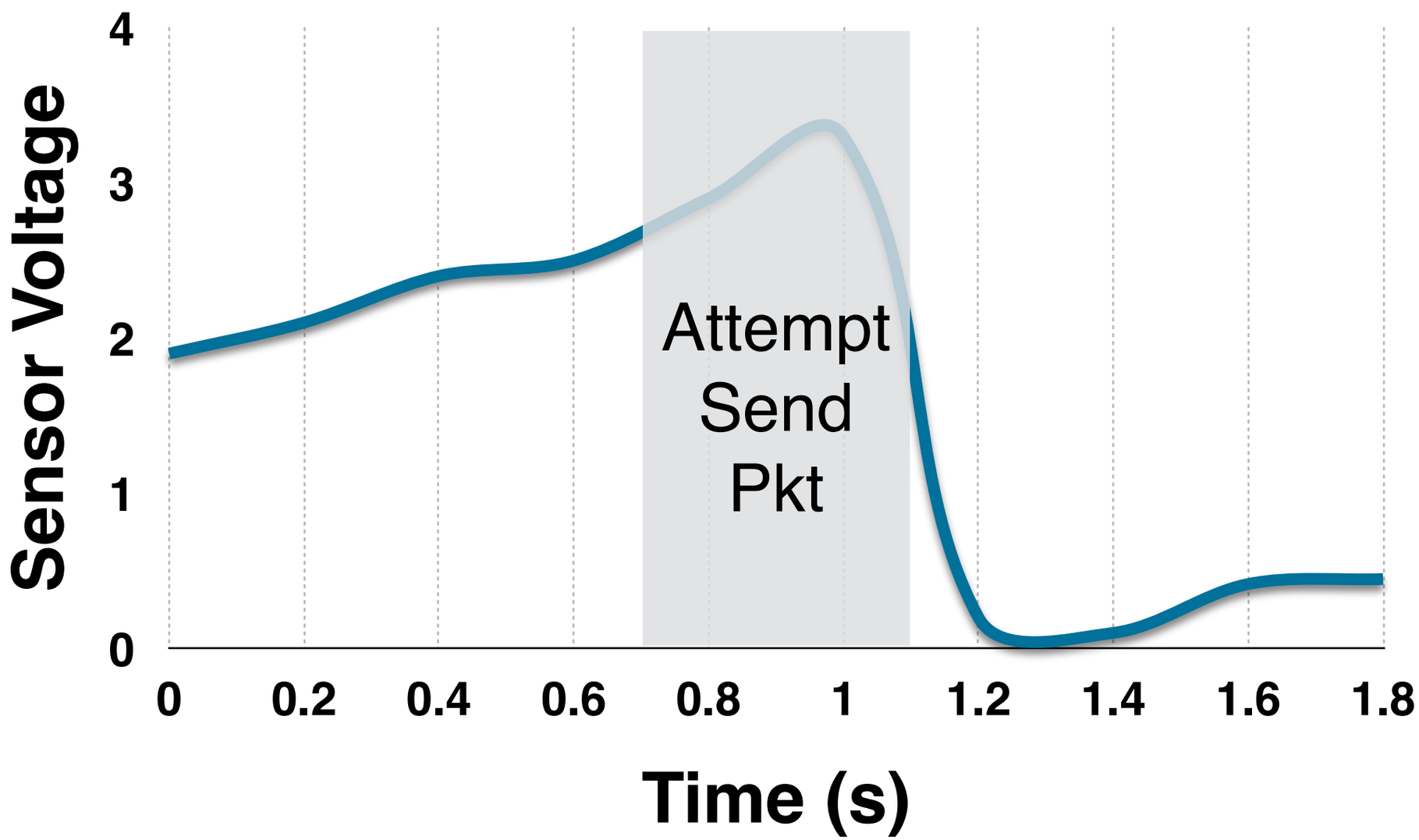

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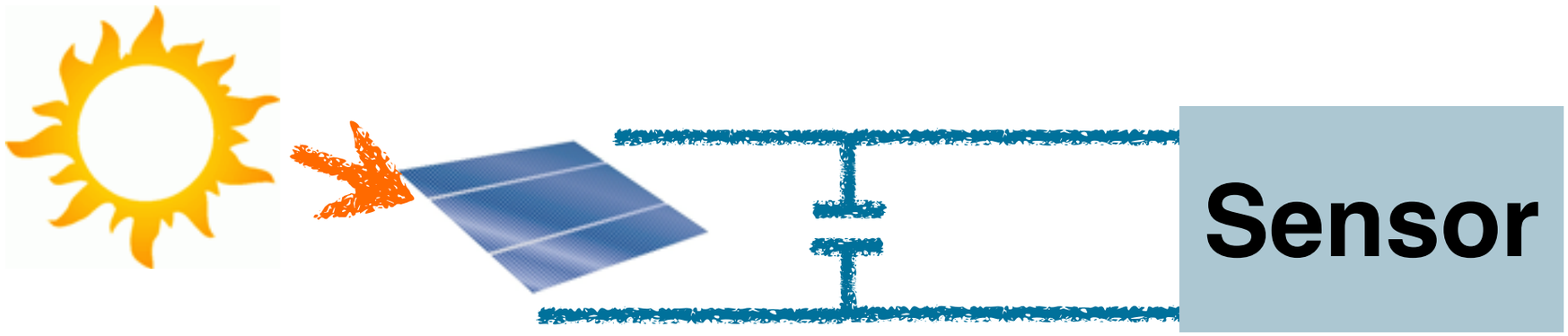

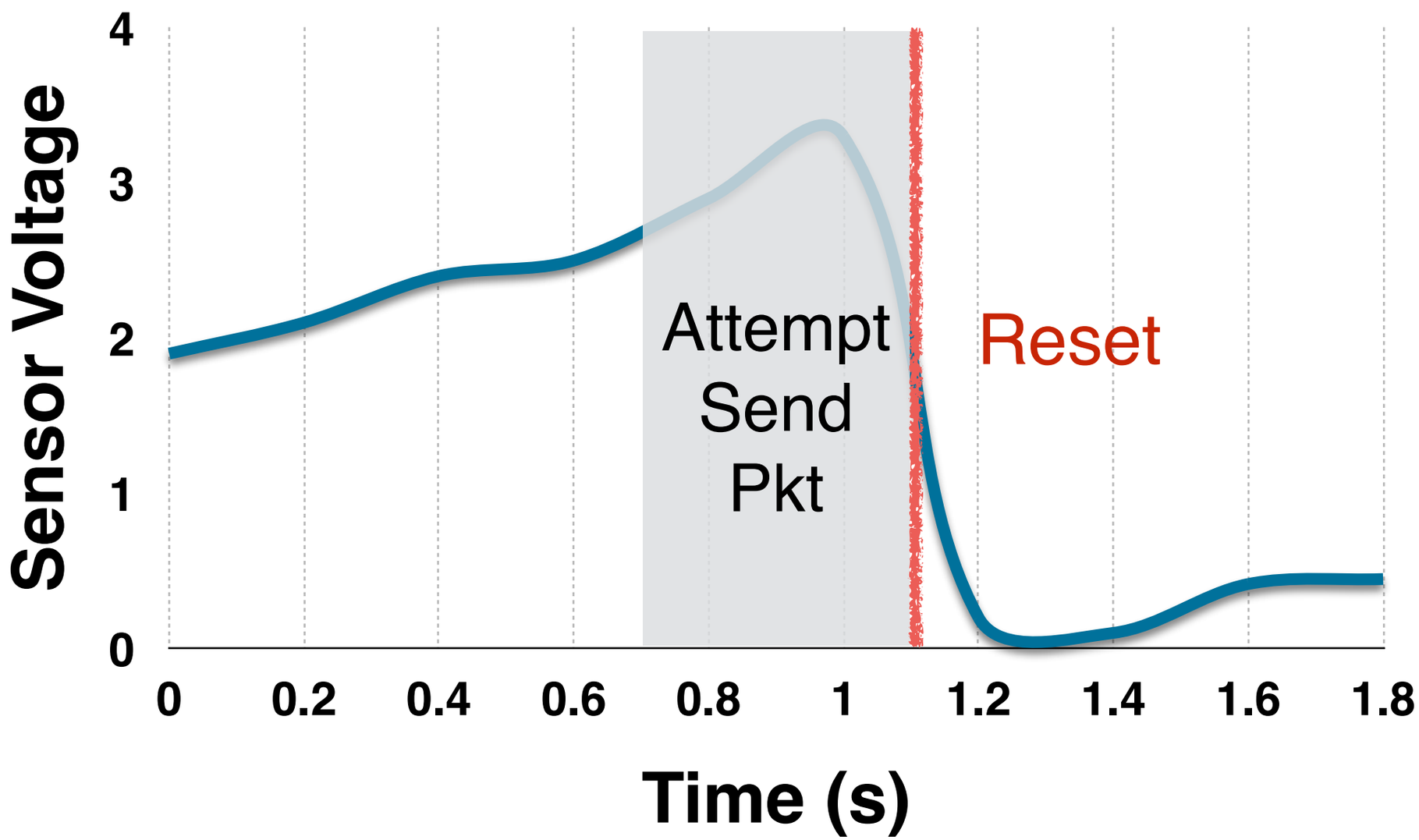

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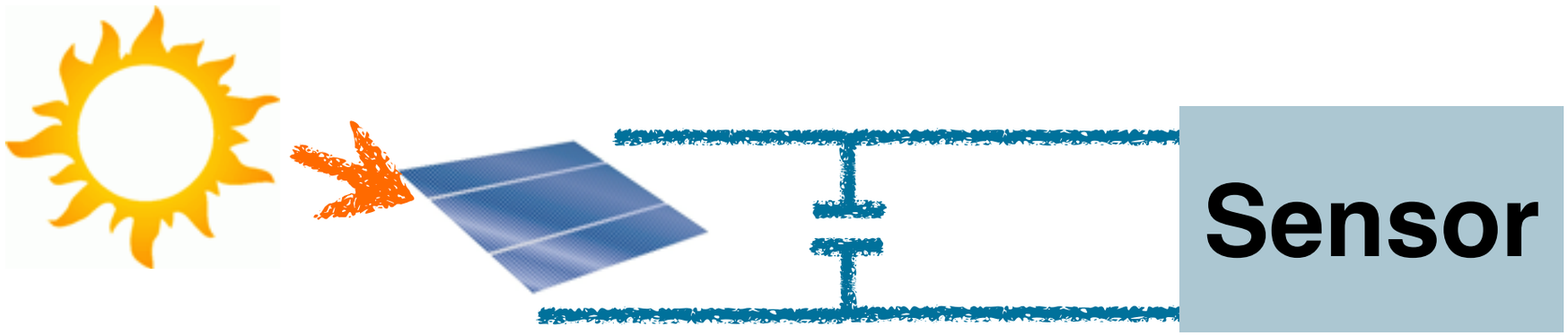
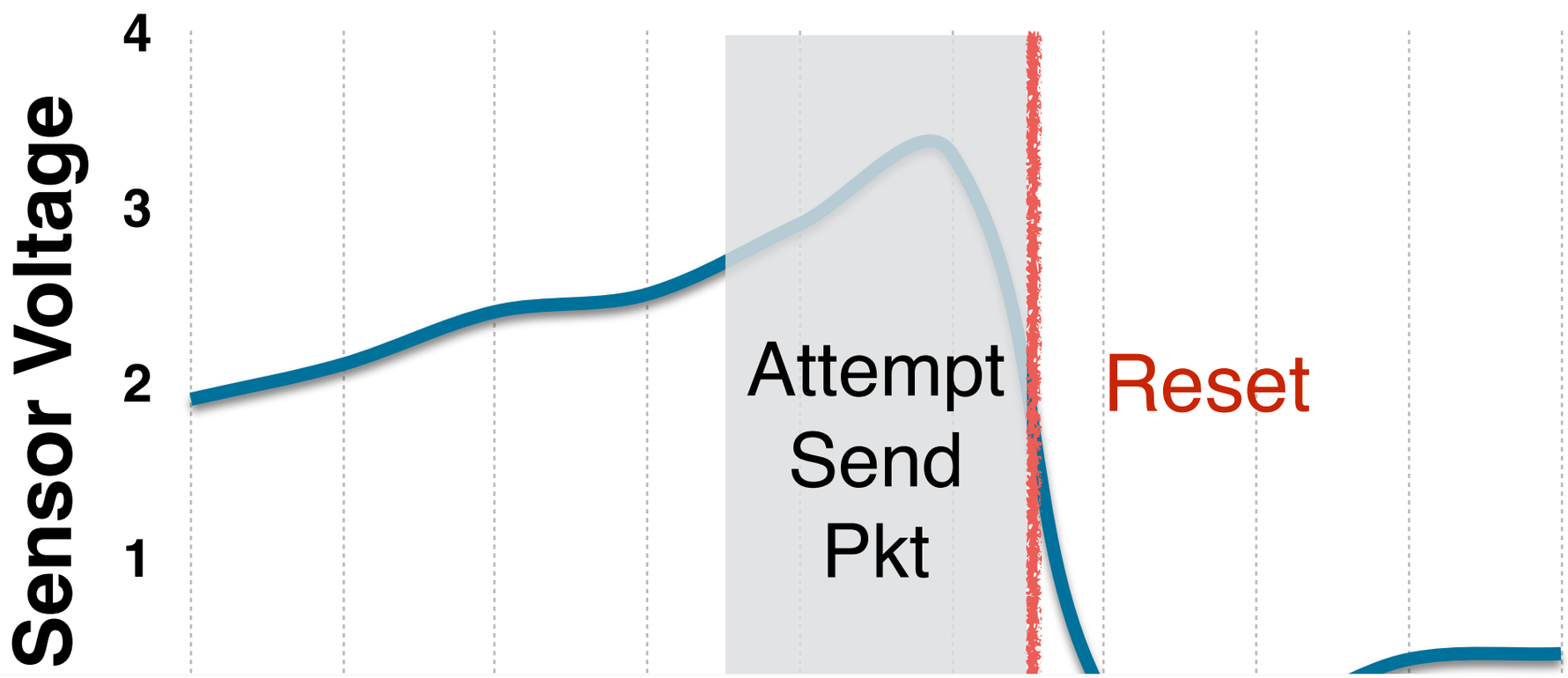
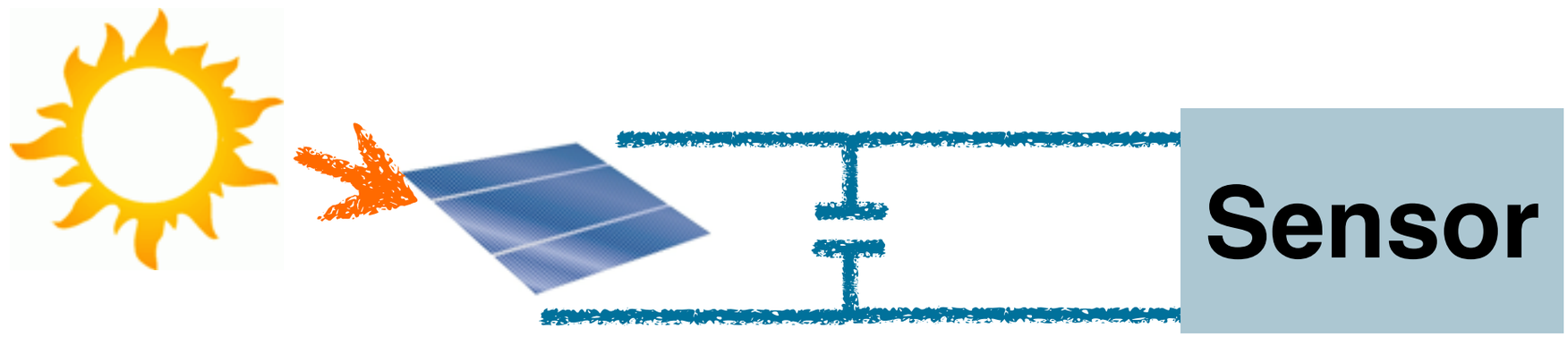
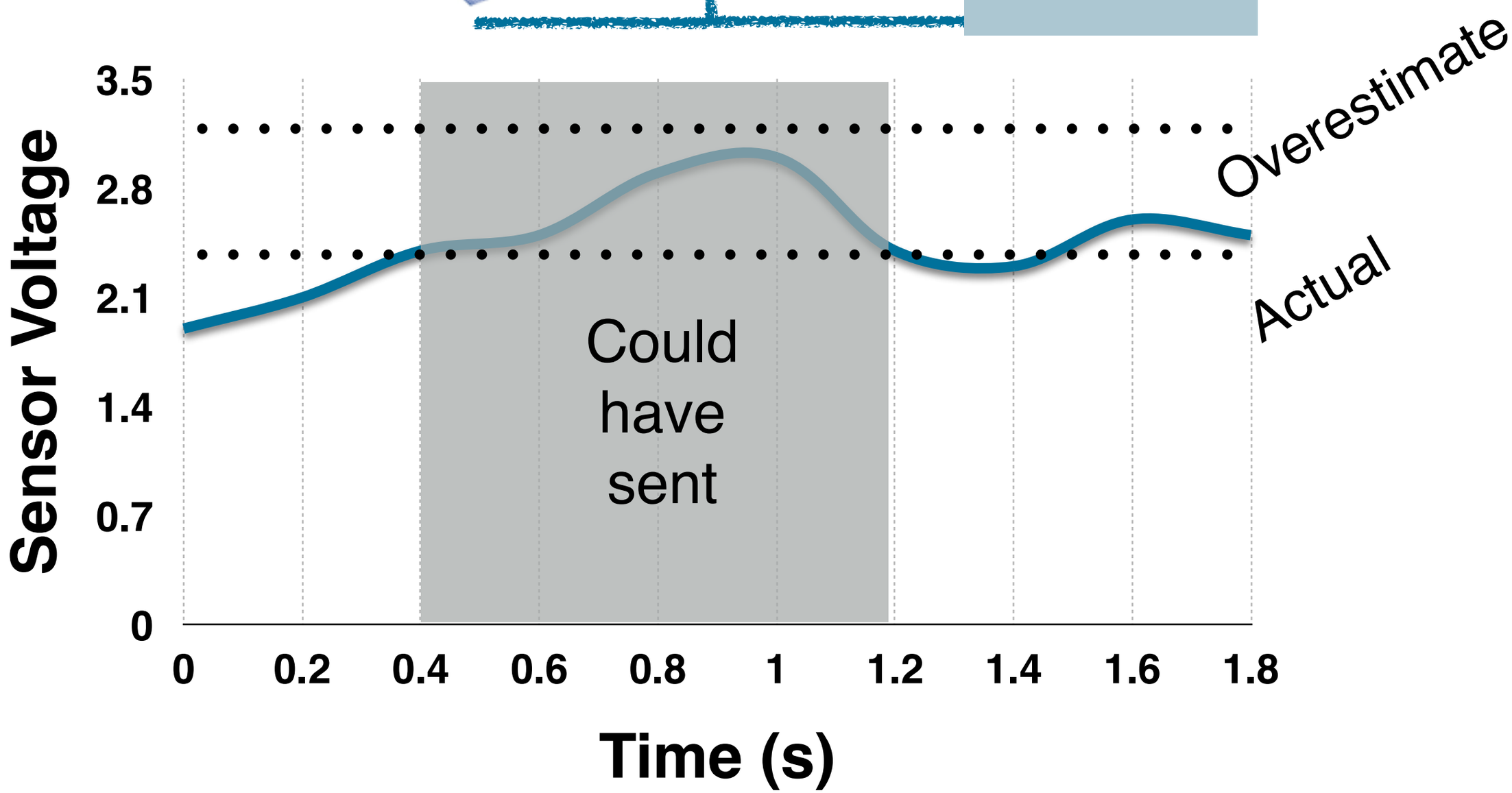




Task coupling increases failure

Batteryless Sensing





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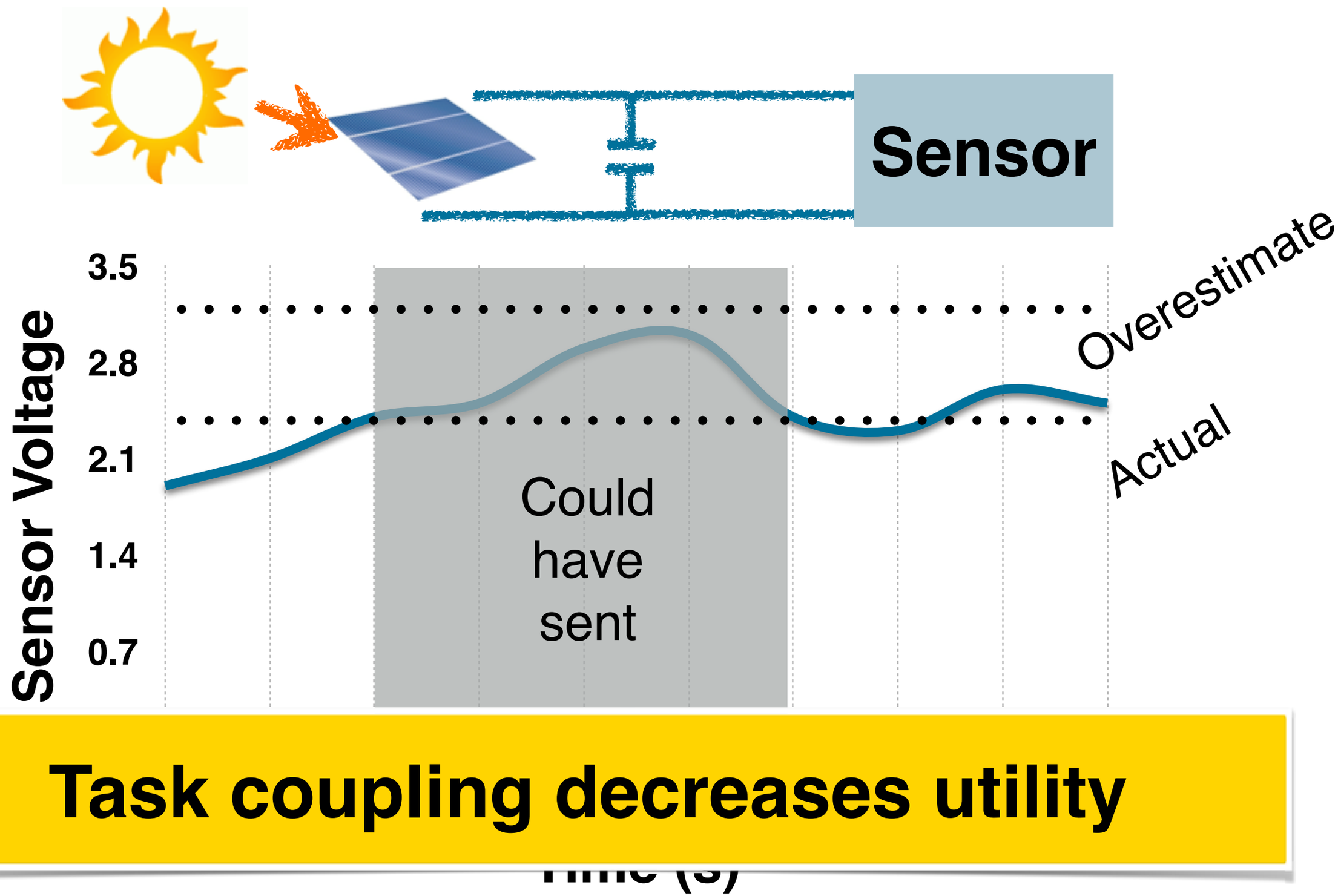
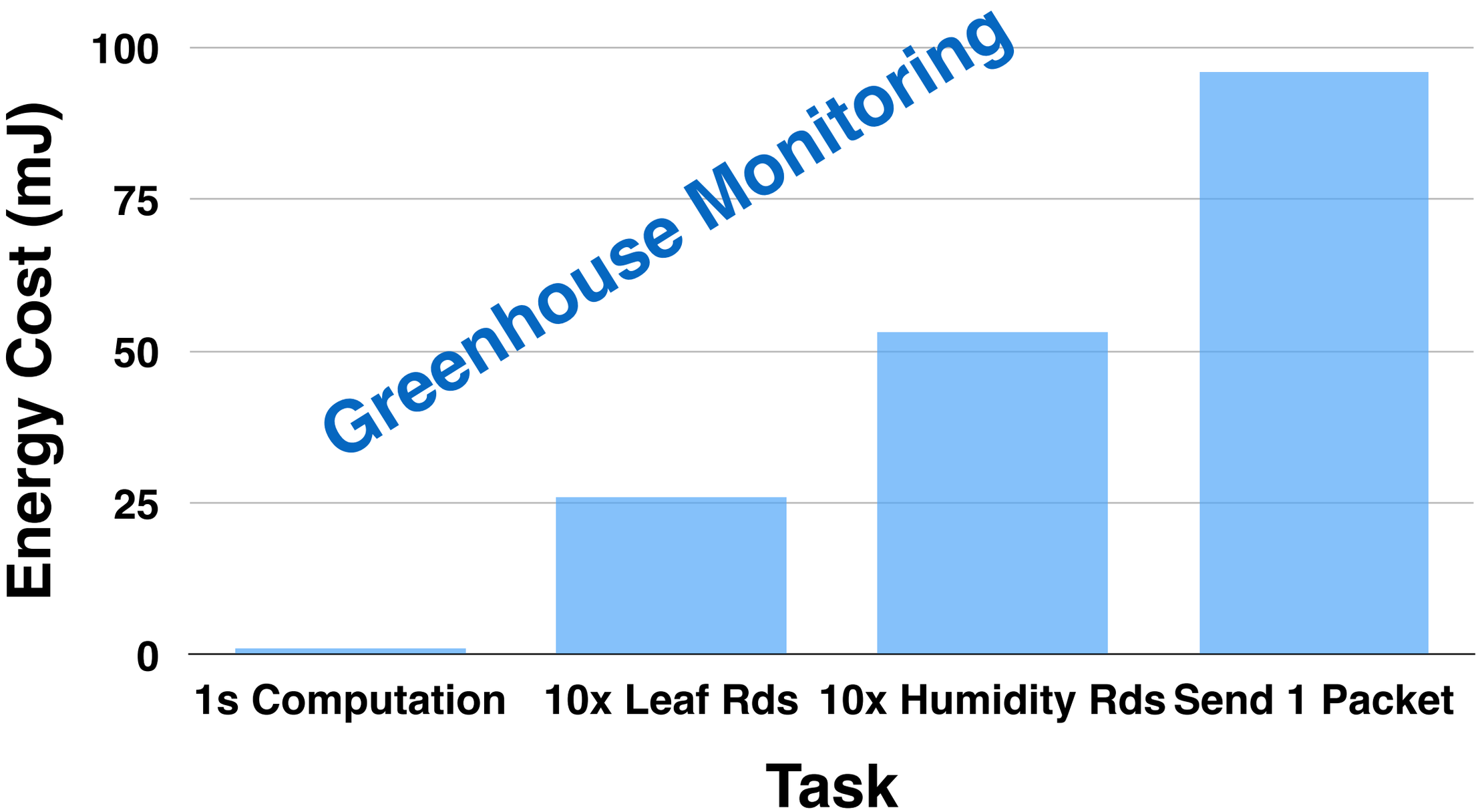


Task coupling decreases utility

Scheduling Tasks



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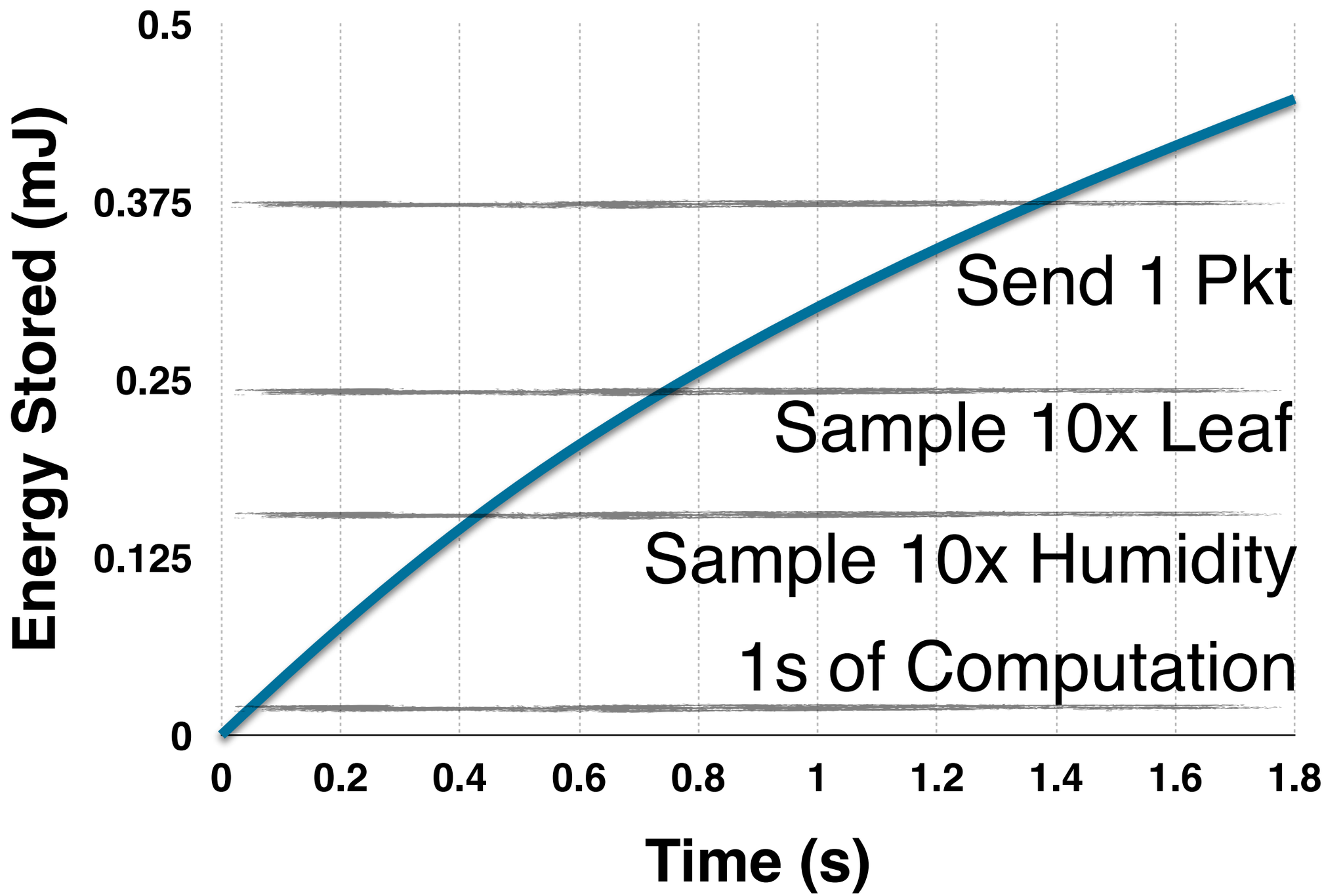

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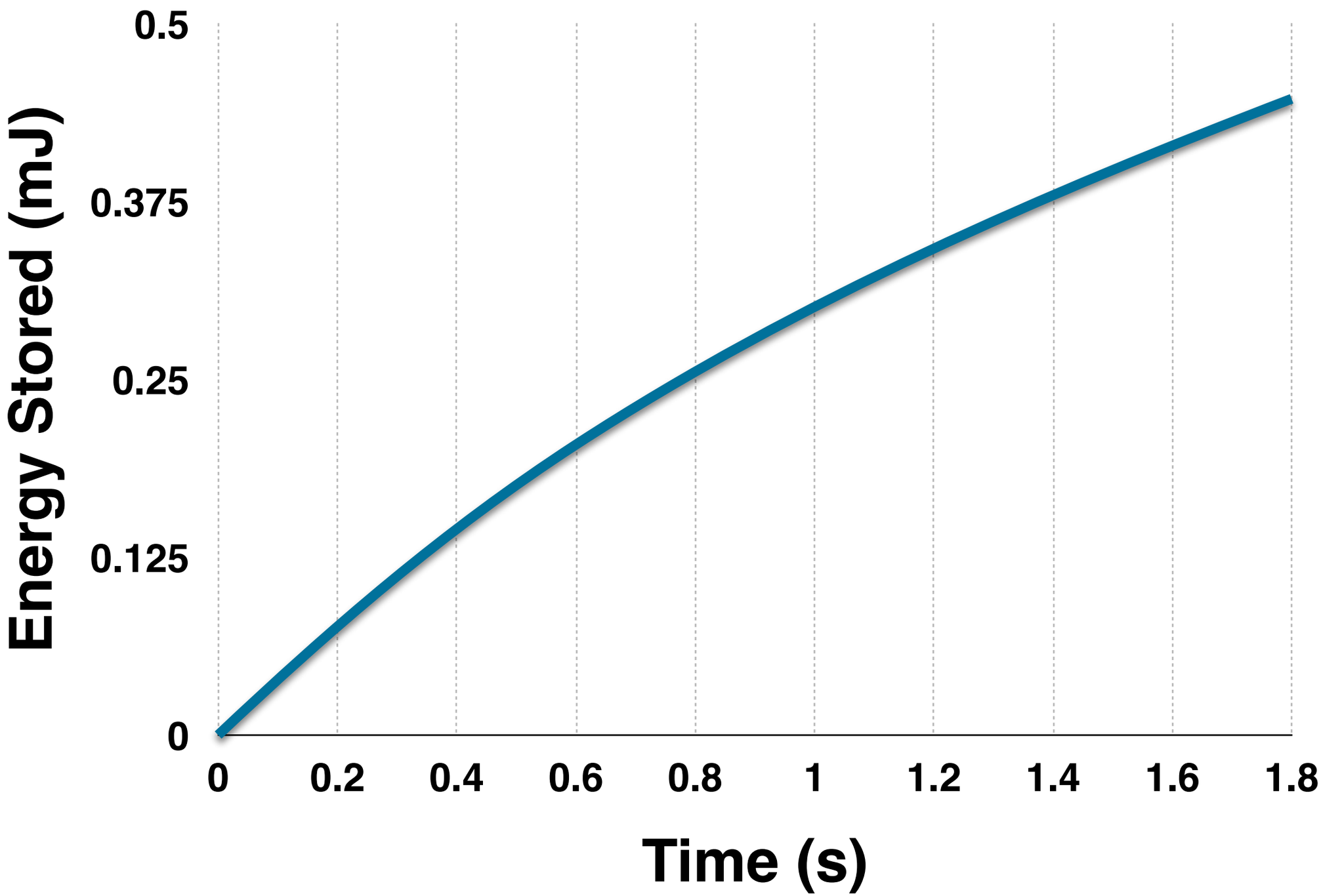

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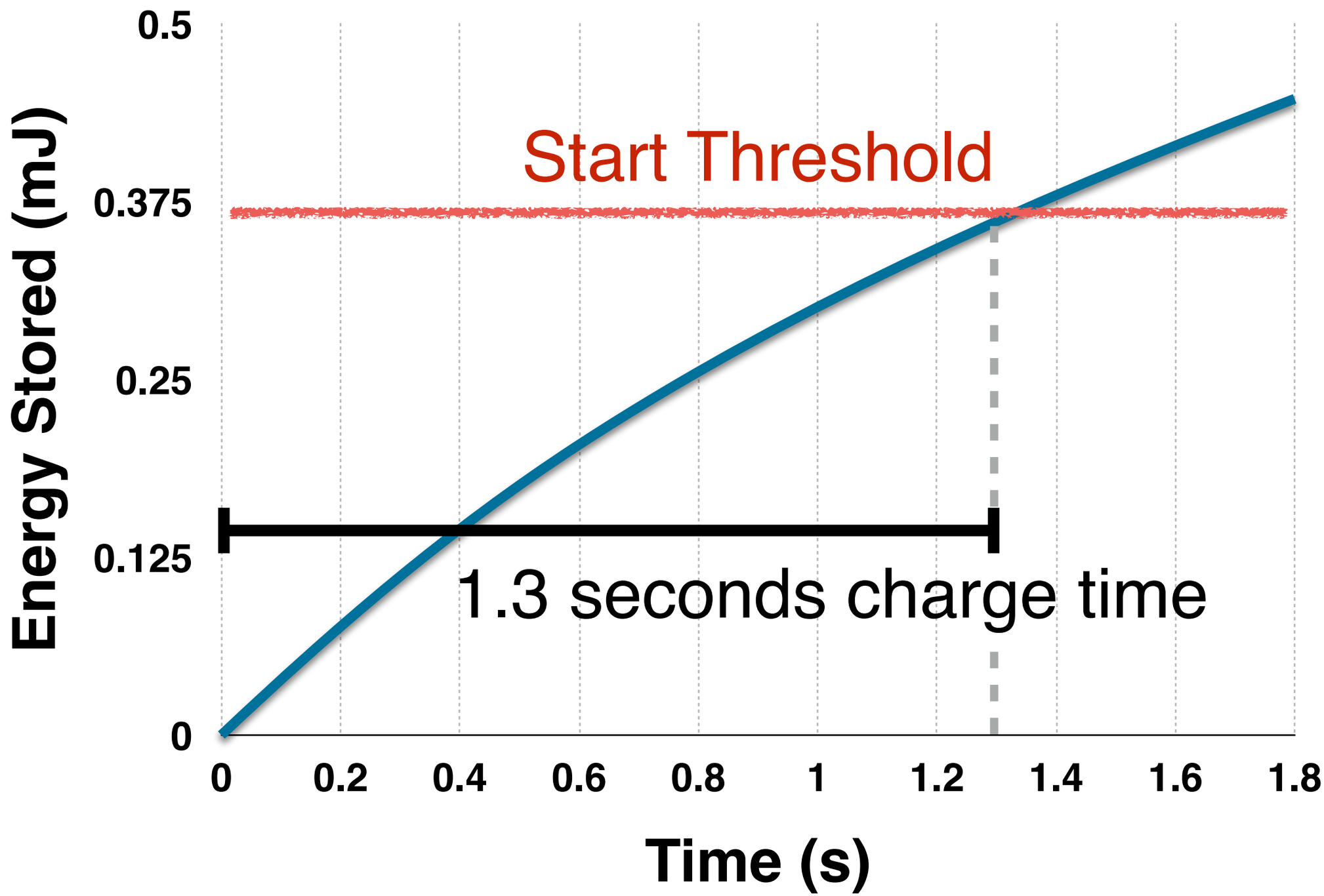

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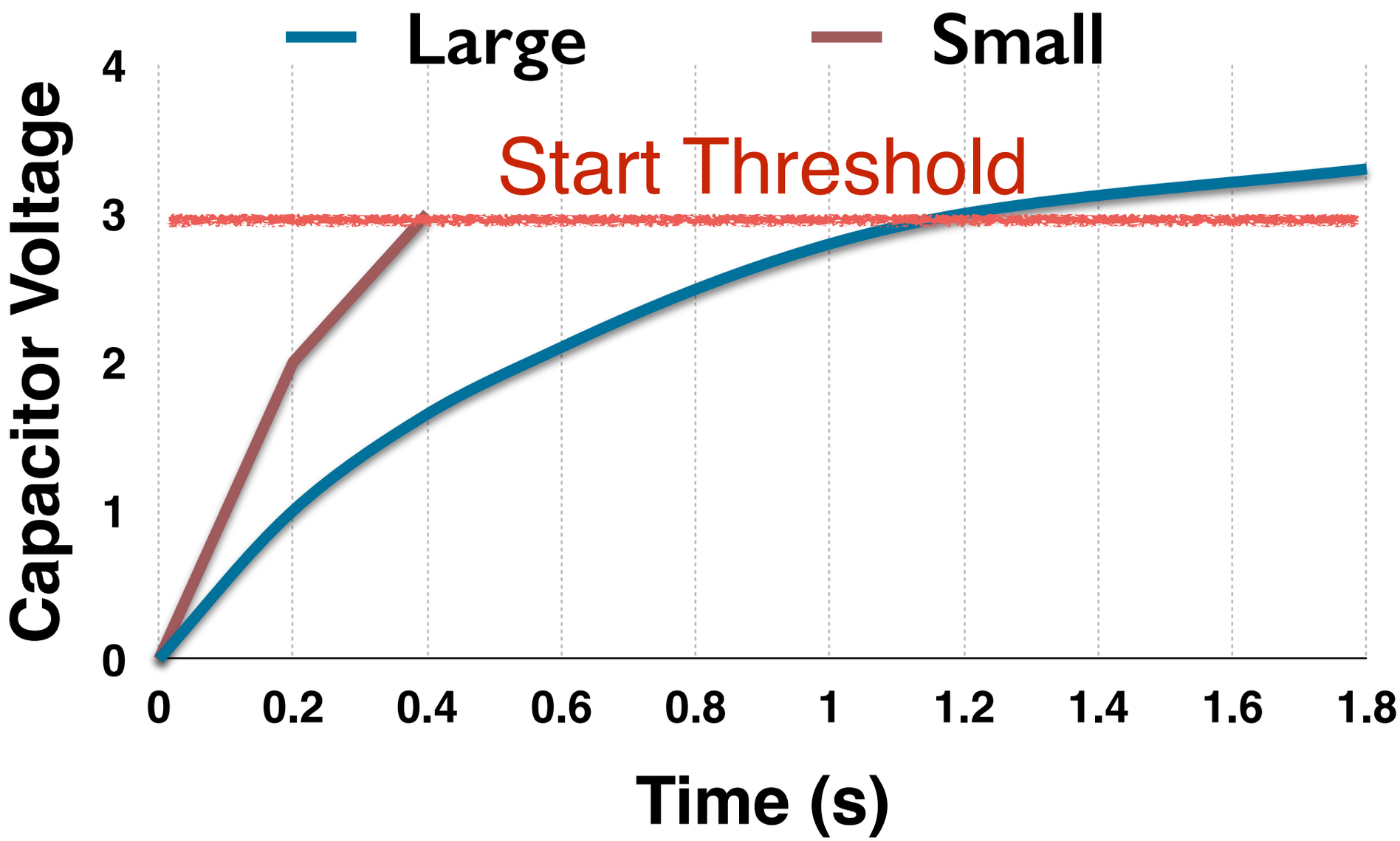

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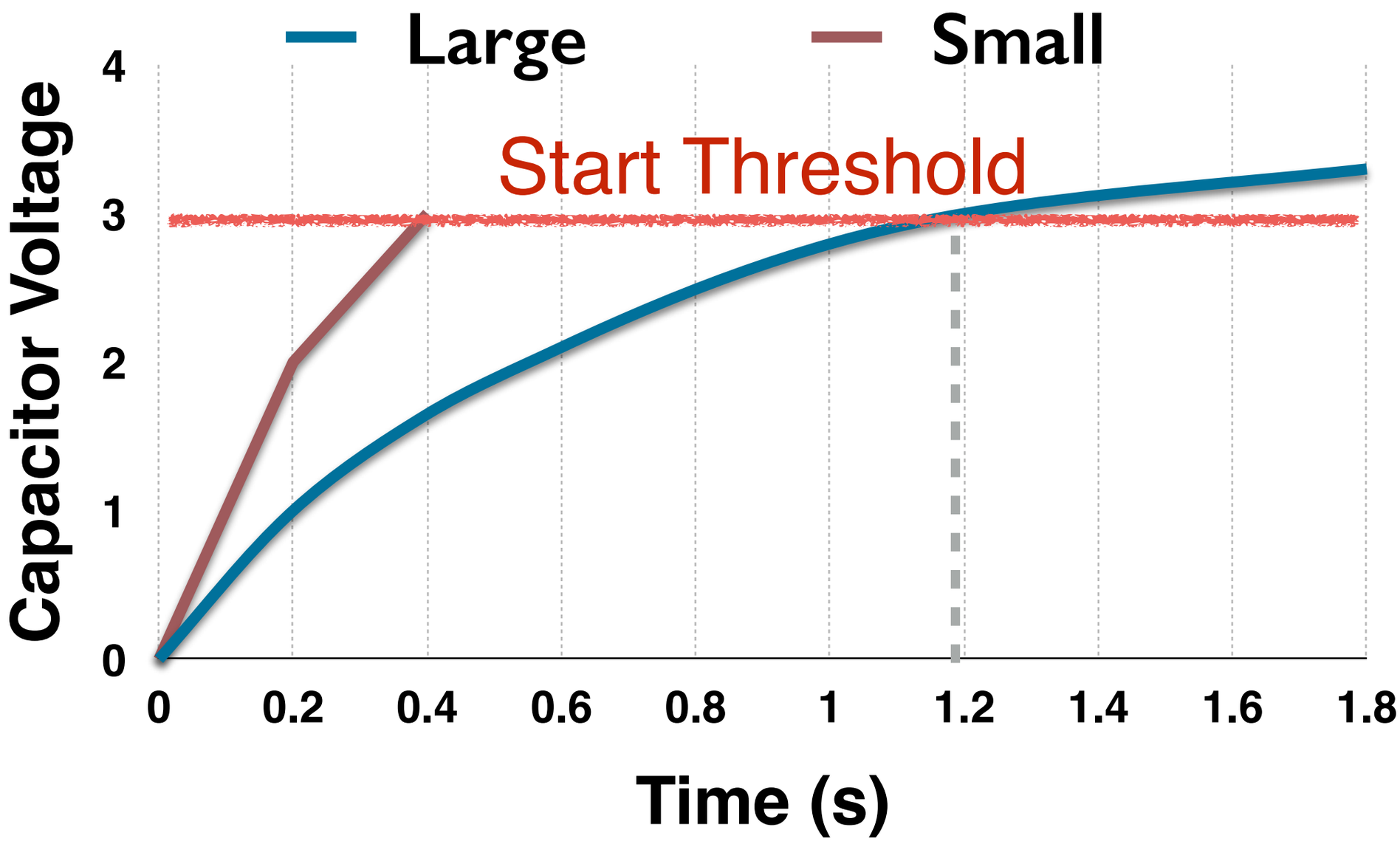
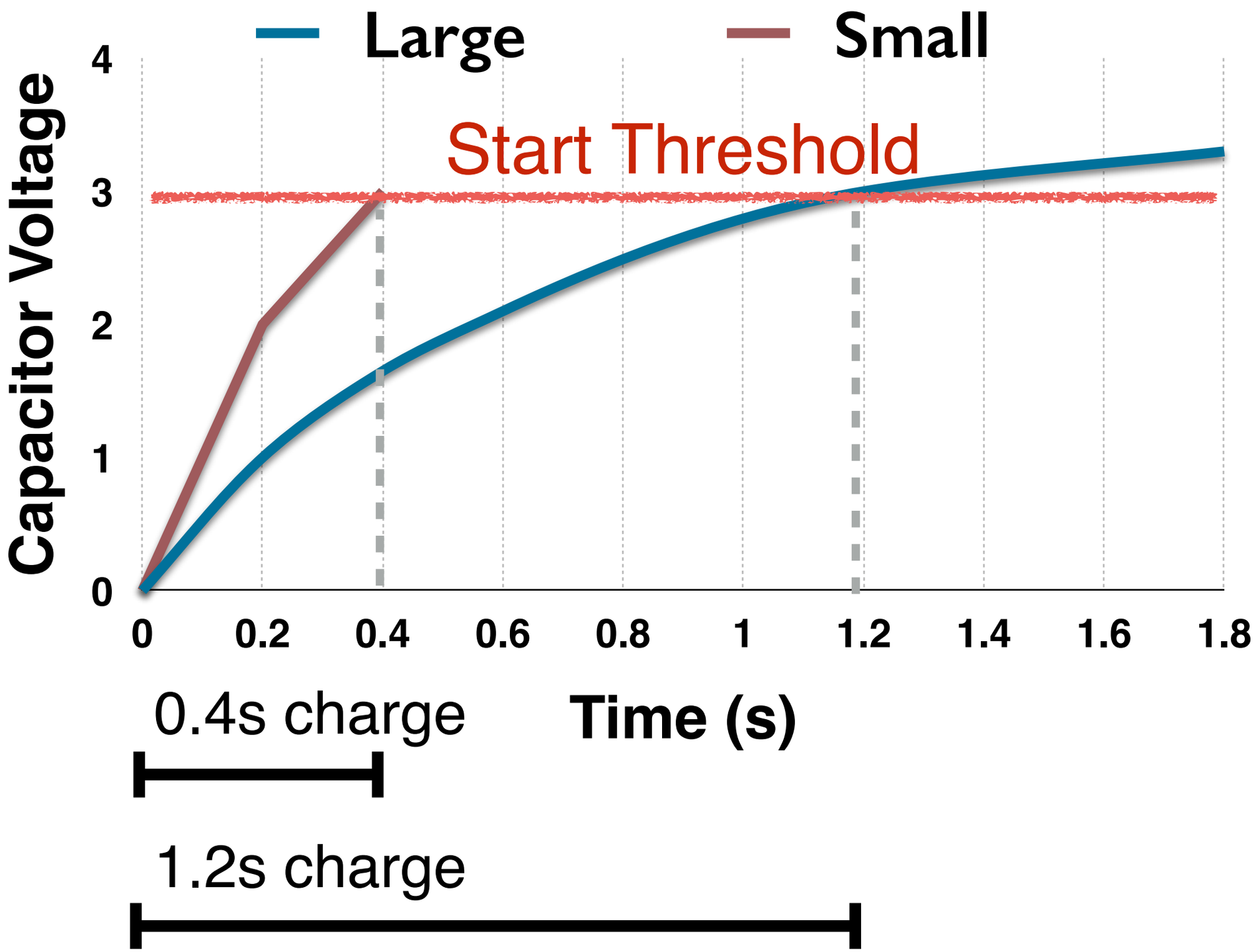


1.2s charge

Scheduling Tasks



Batteryless Sensing

Batteryless sensing is hard

- Tasks are coupled, causing death
- Execution is not predictable
- Low energy tasks wait on high energy tasks

Because energy storage is centralized

Batteryless Sensing

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- Tasks are coupled, causing death
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Because energy storage is centralized

What if we federate energy storage?

Federated Energy

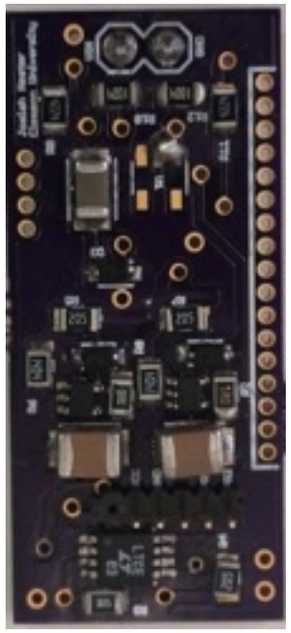
Benefits

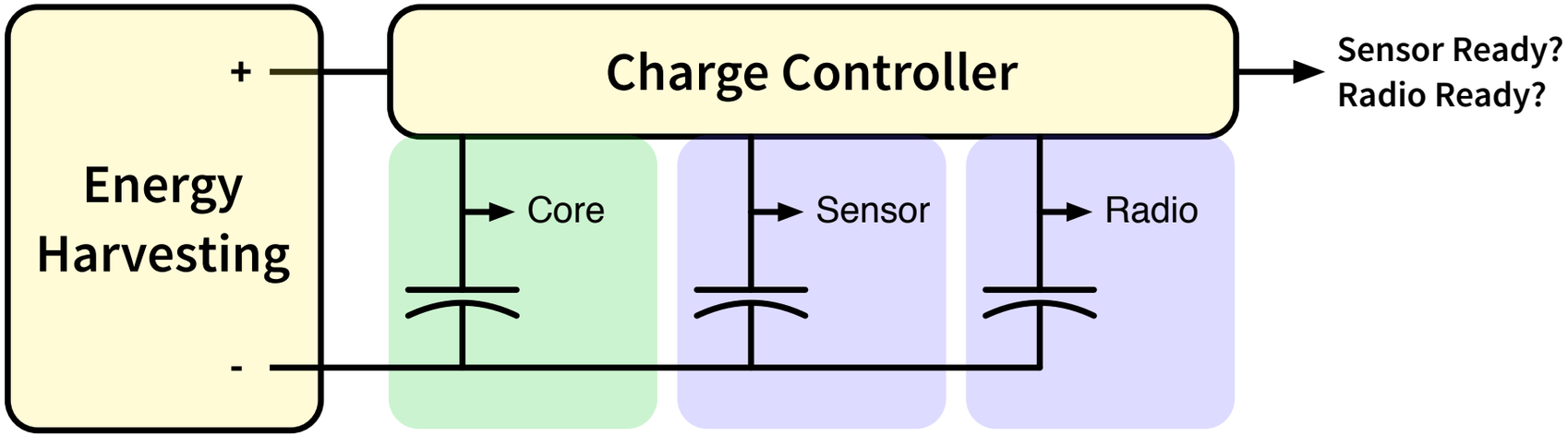
- useful work starts sooner
- fewer power failures
- simpler application decisions
- relaxes voltage coupling
- increases energy harvested

UFoP

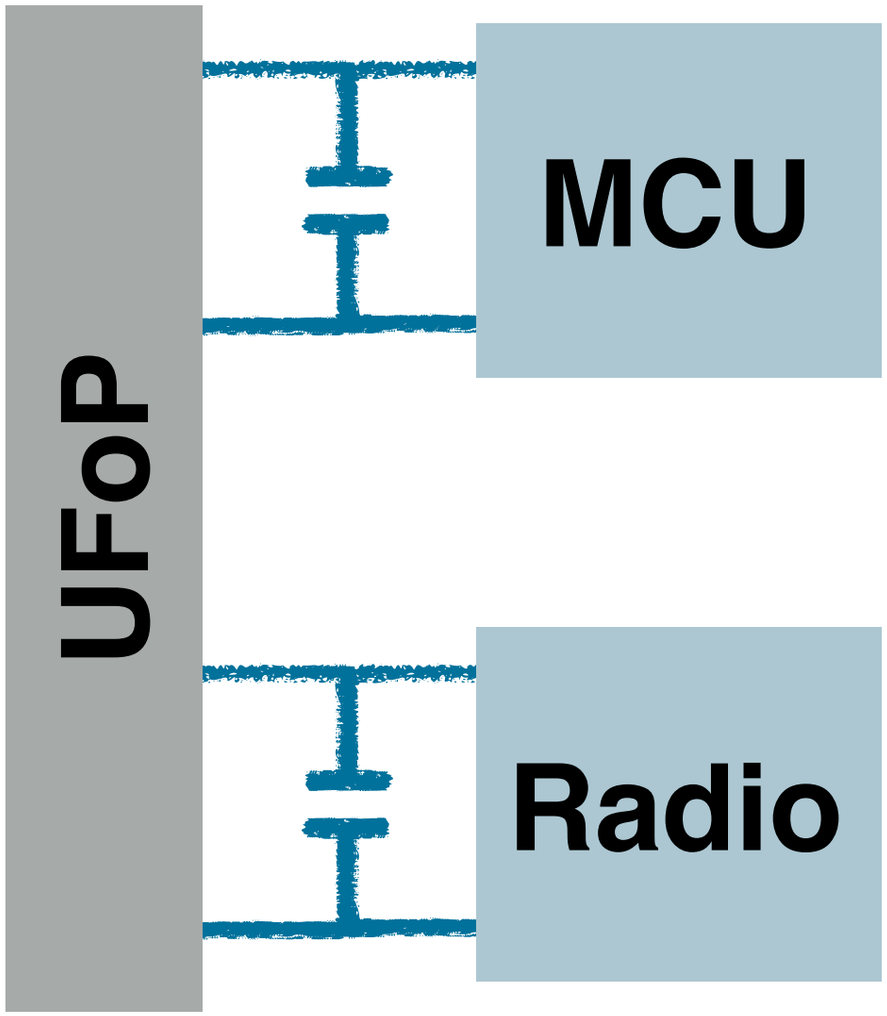
Multiple capacitors

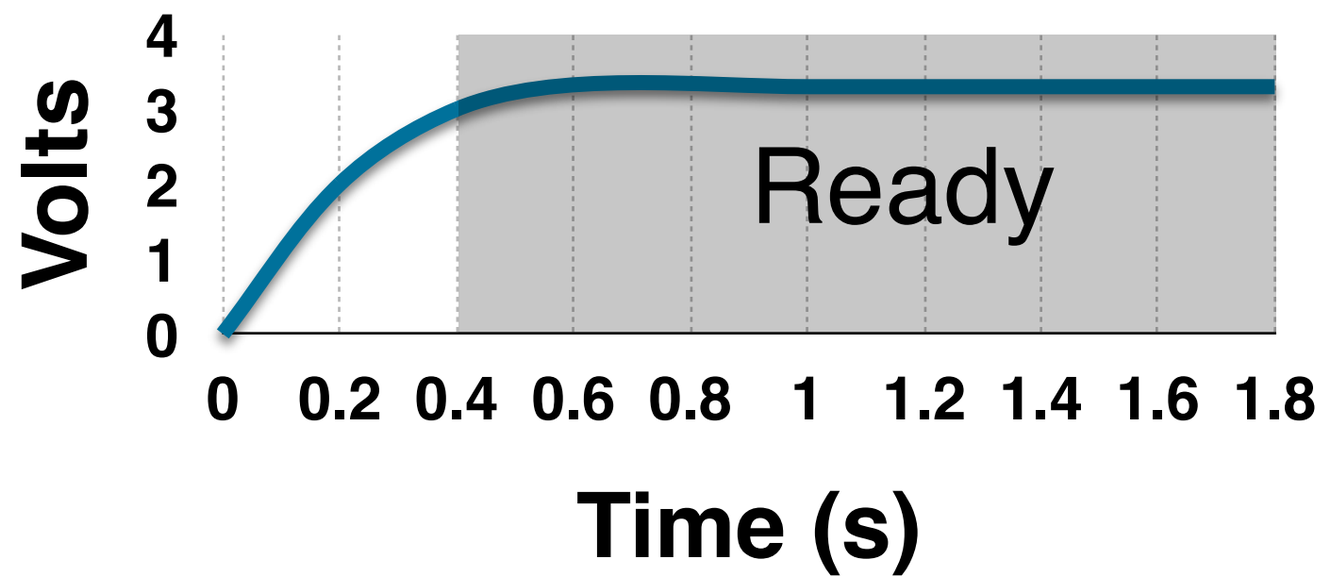
- One for microcontroller
- One for each peripheral
- Static rate and priority

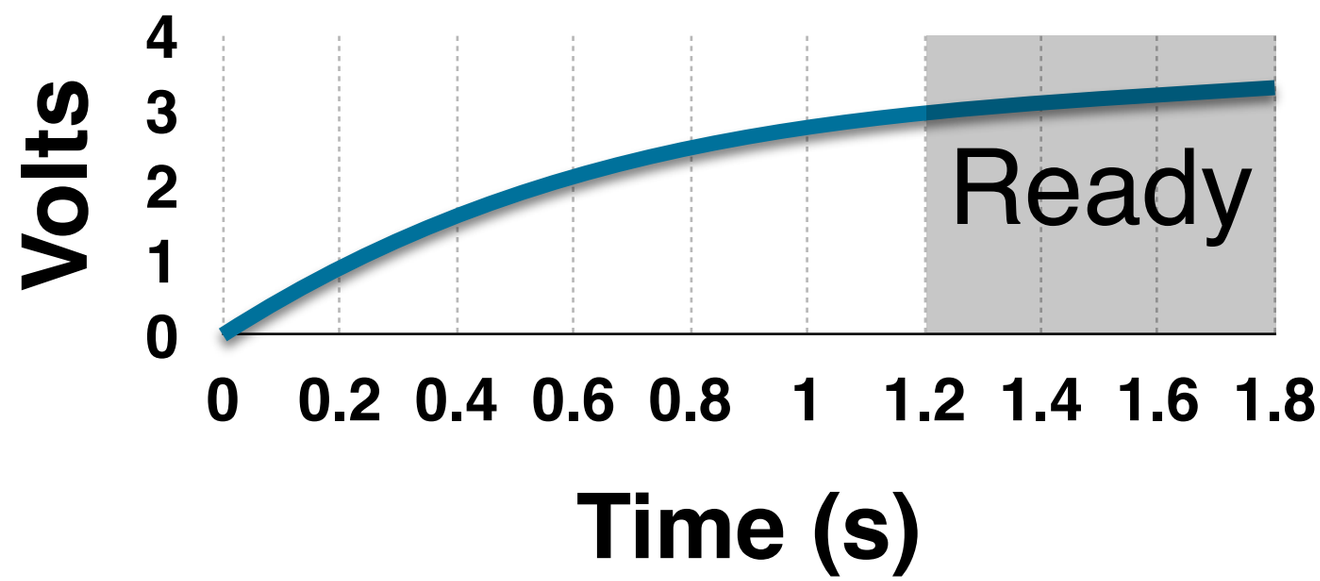




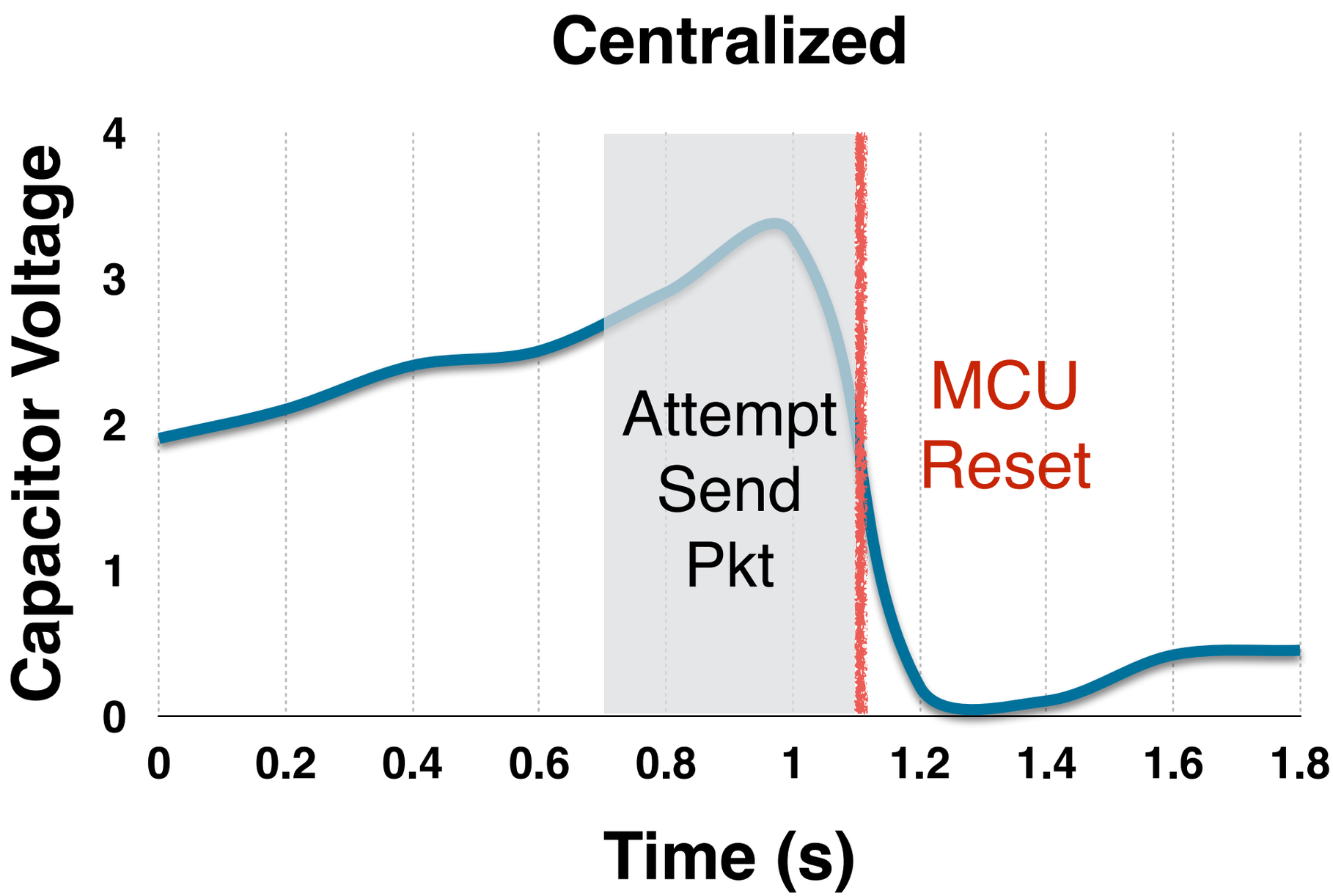
Start work sooner



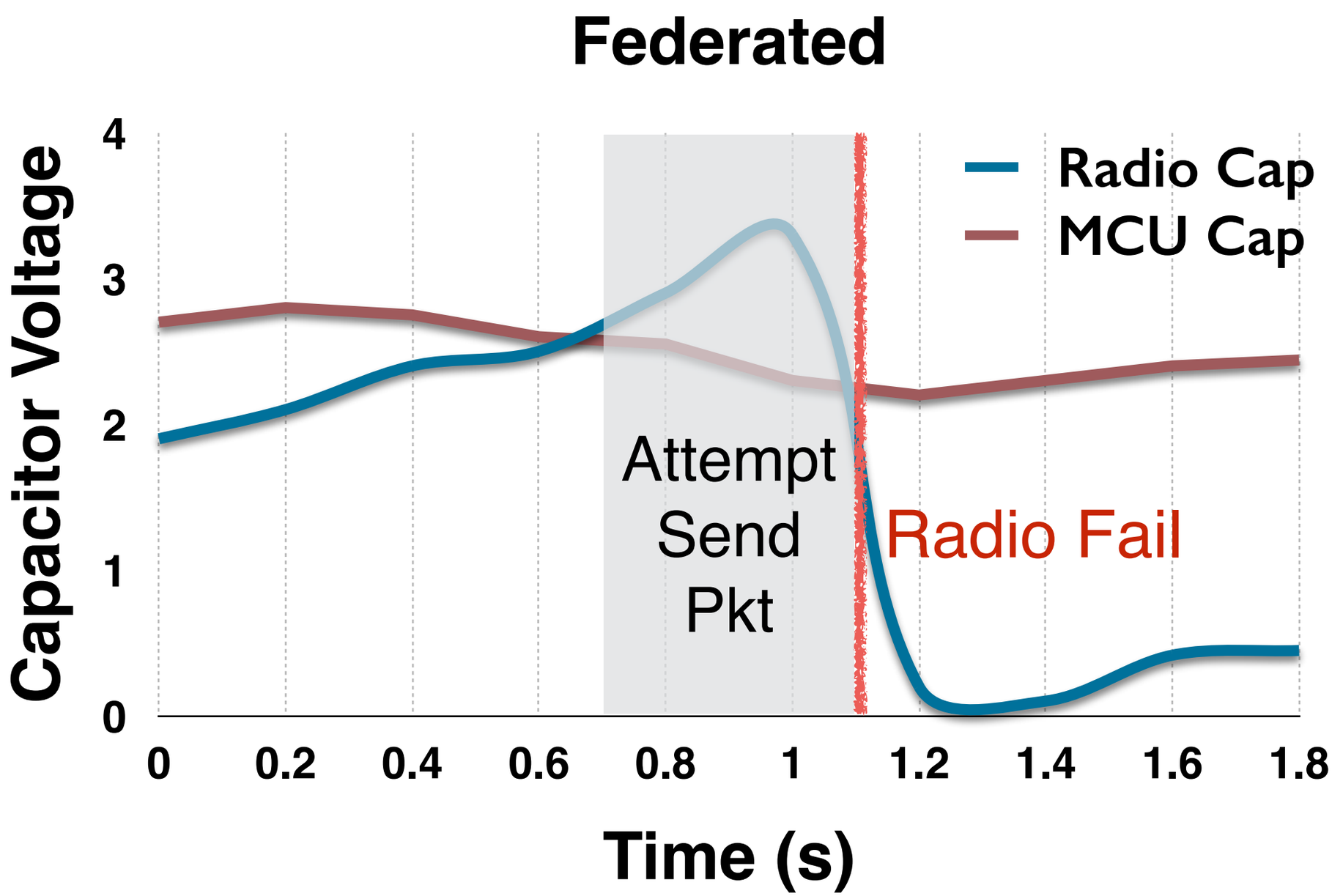




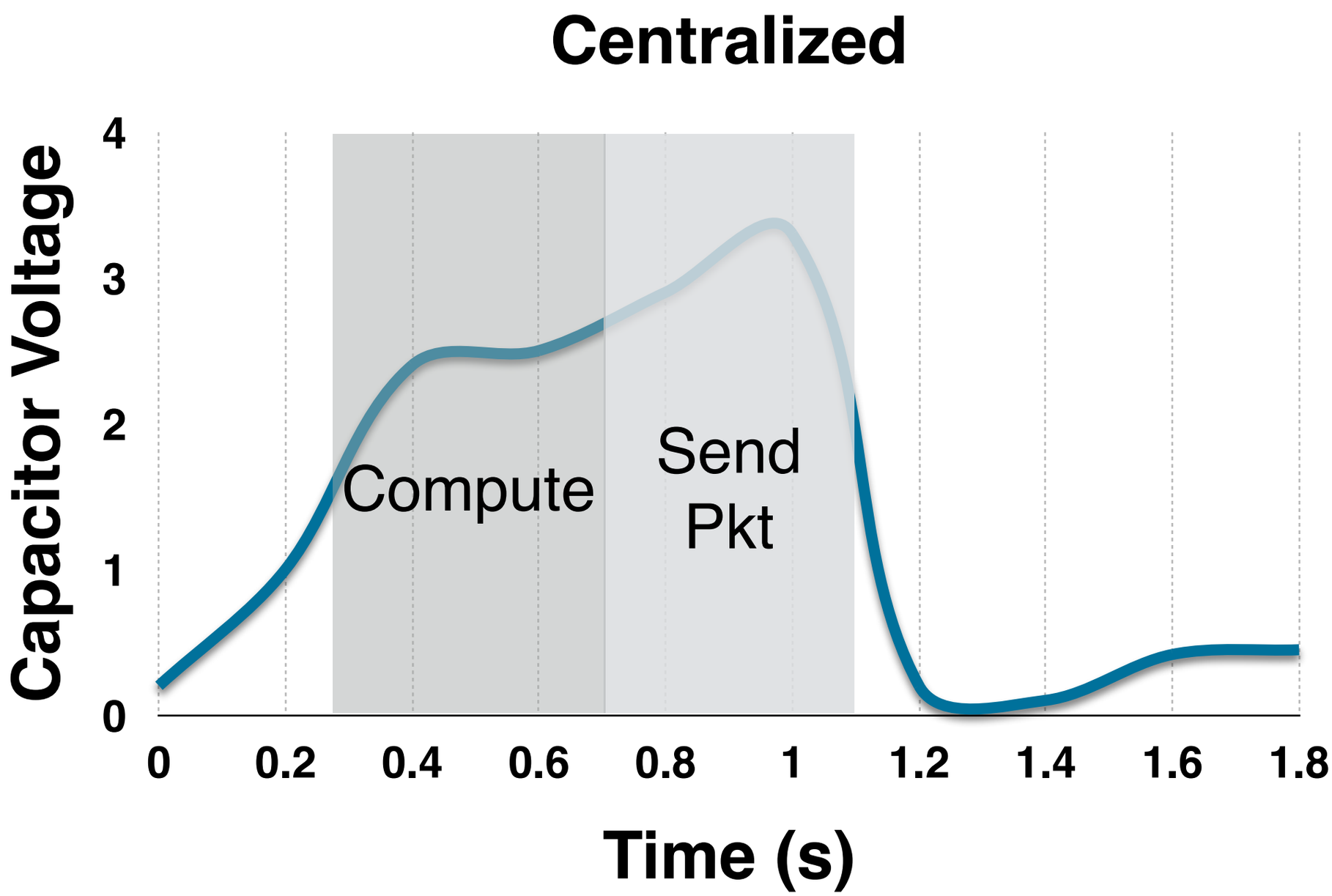
Decrease power failures



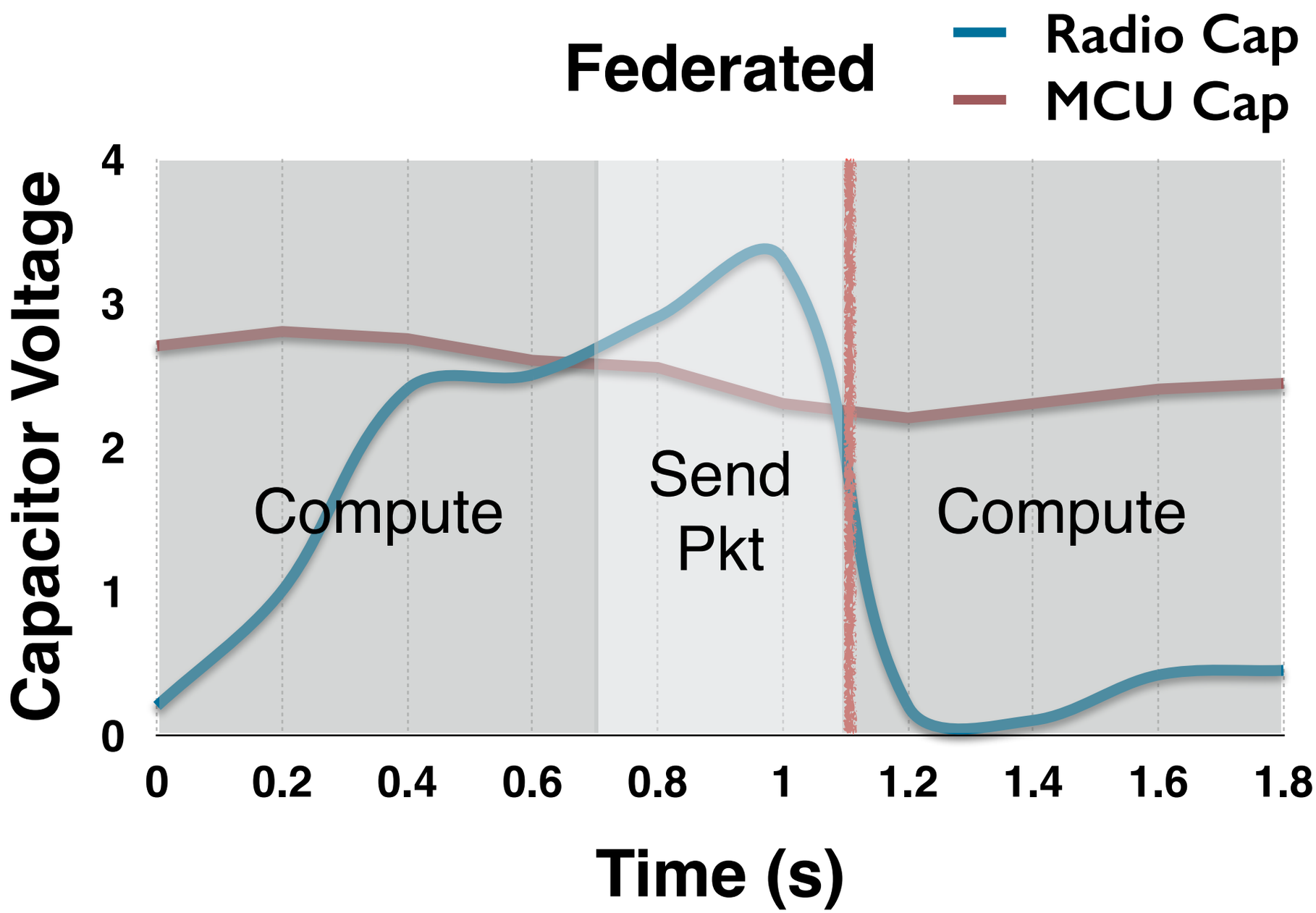
Decrease power failures



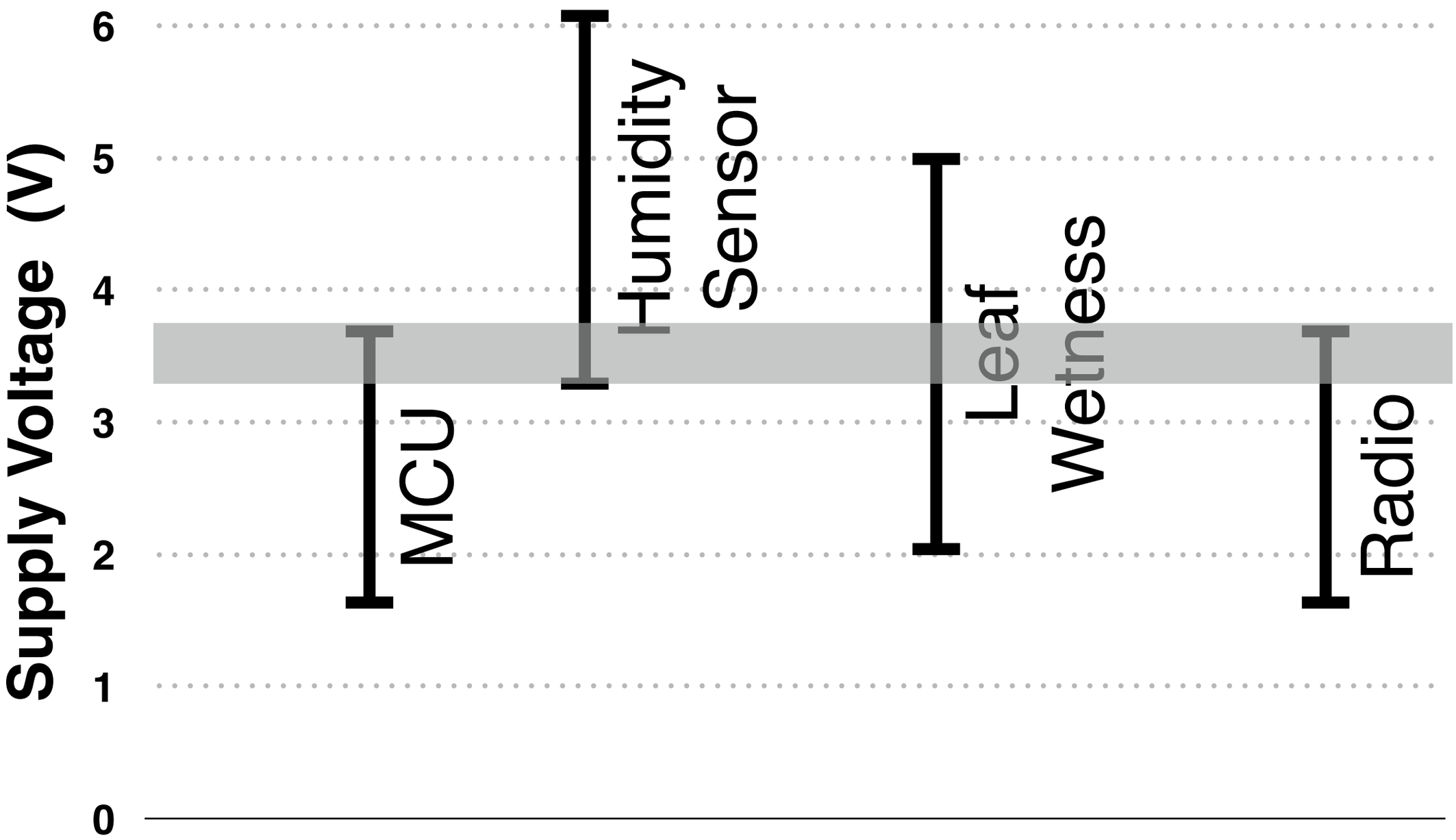
Simplify app decisions



Simplify app decisions



Relax voltage constraints



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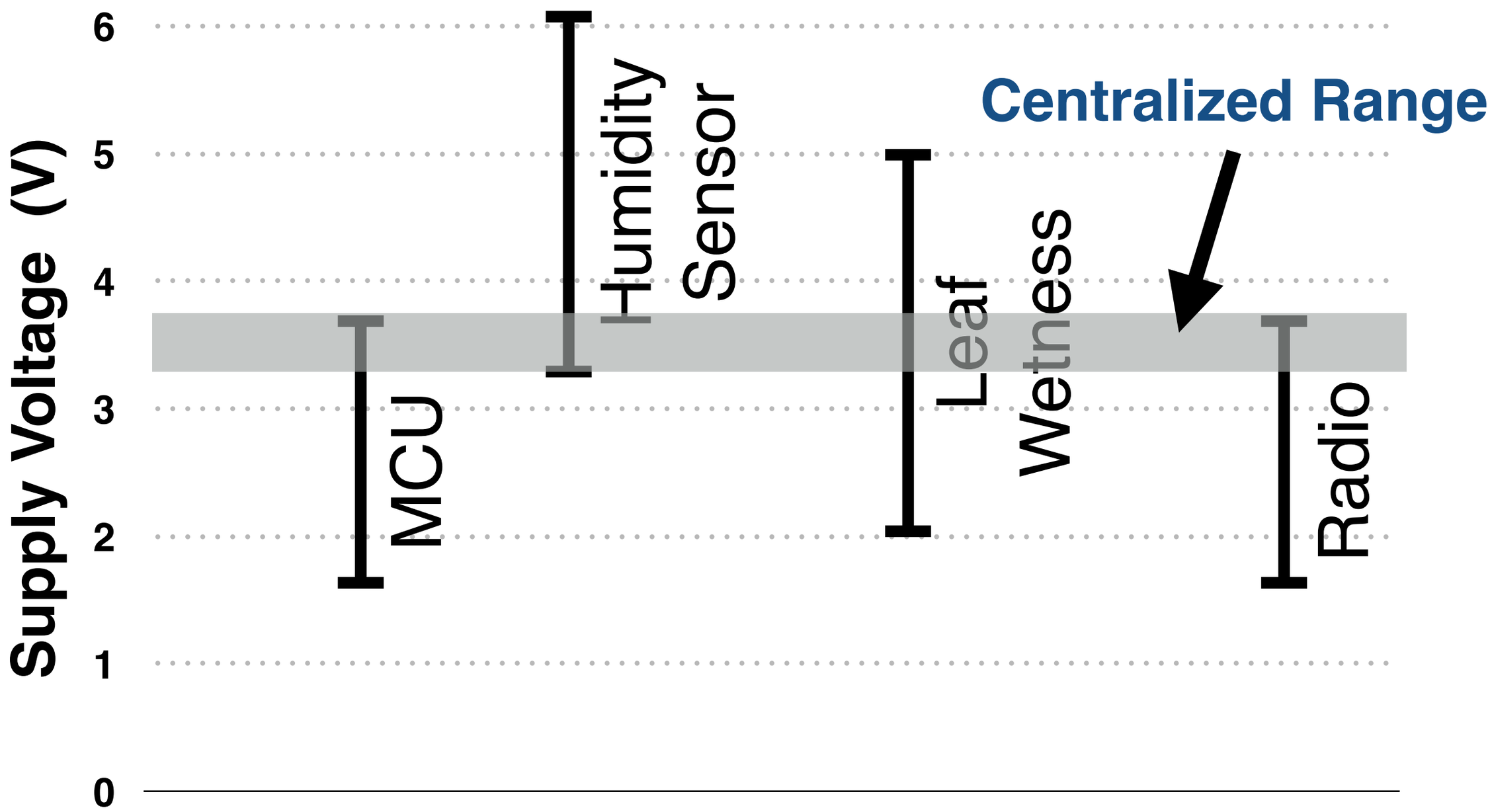

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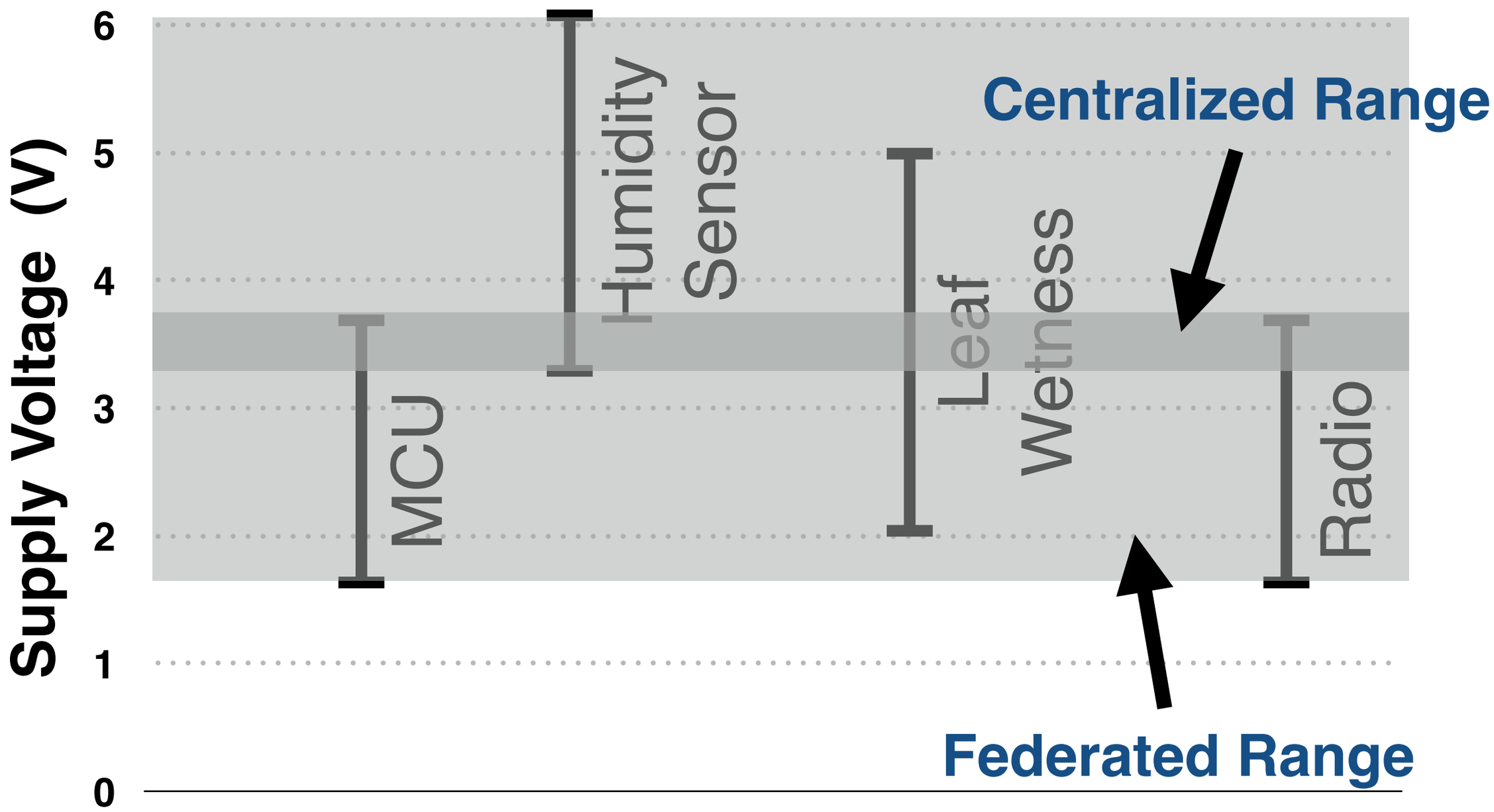
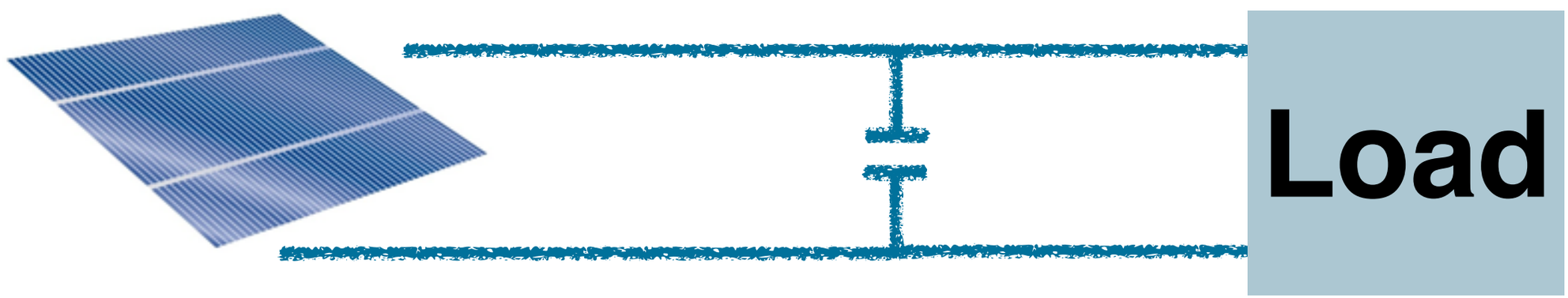


Harvest more energy



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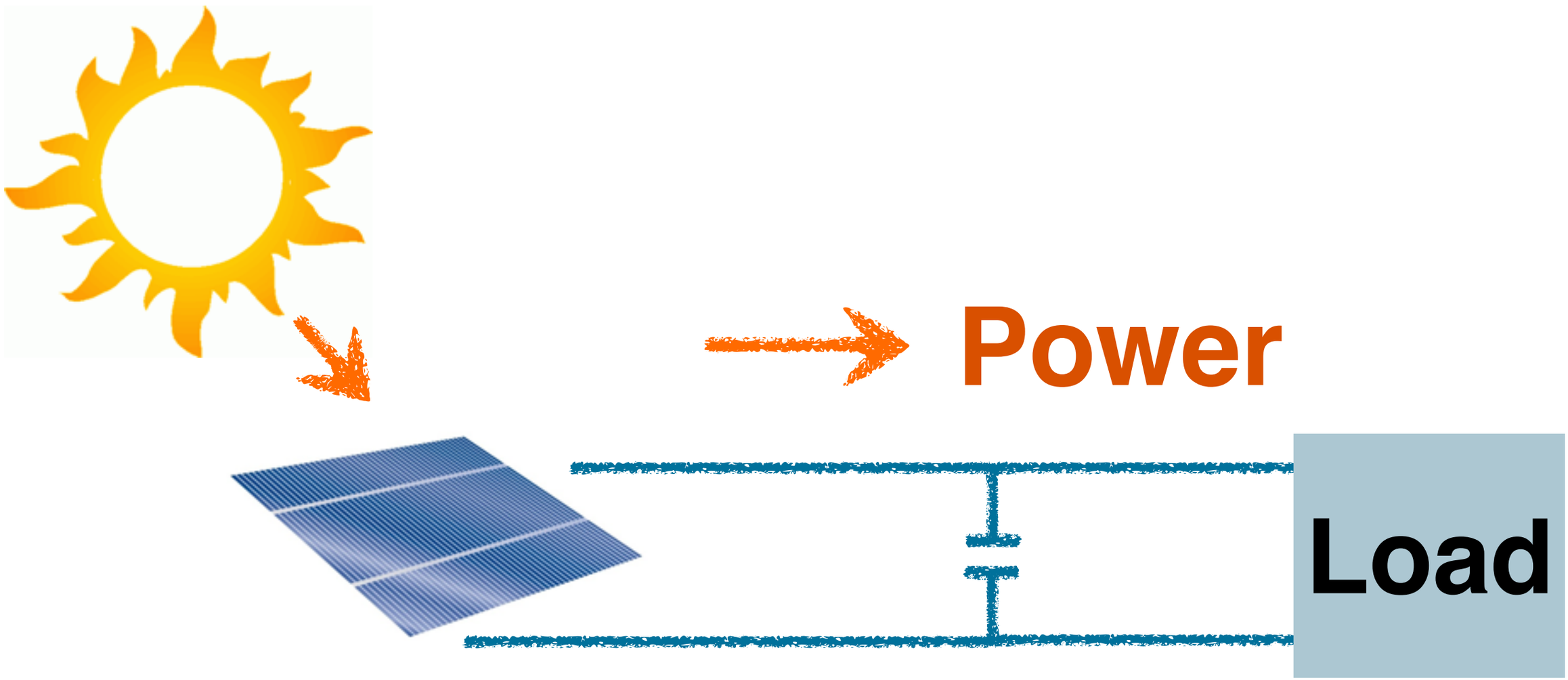

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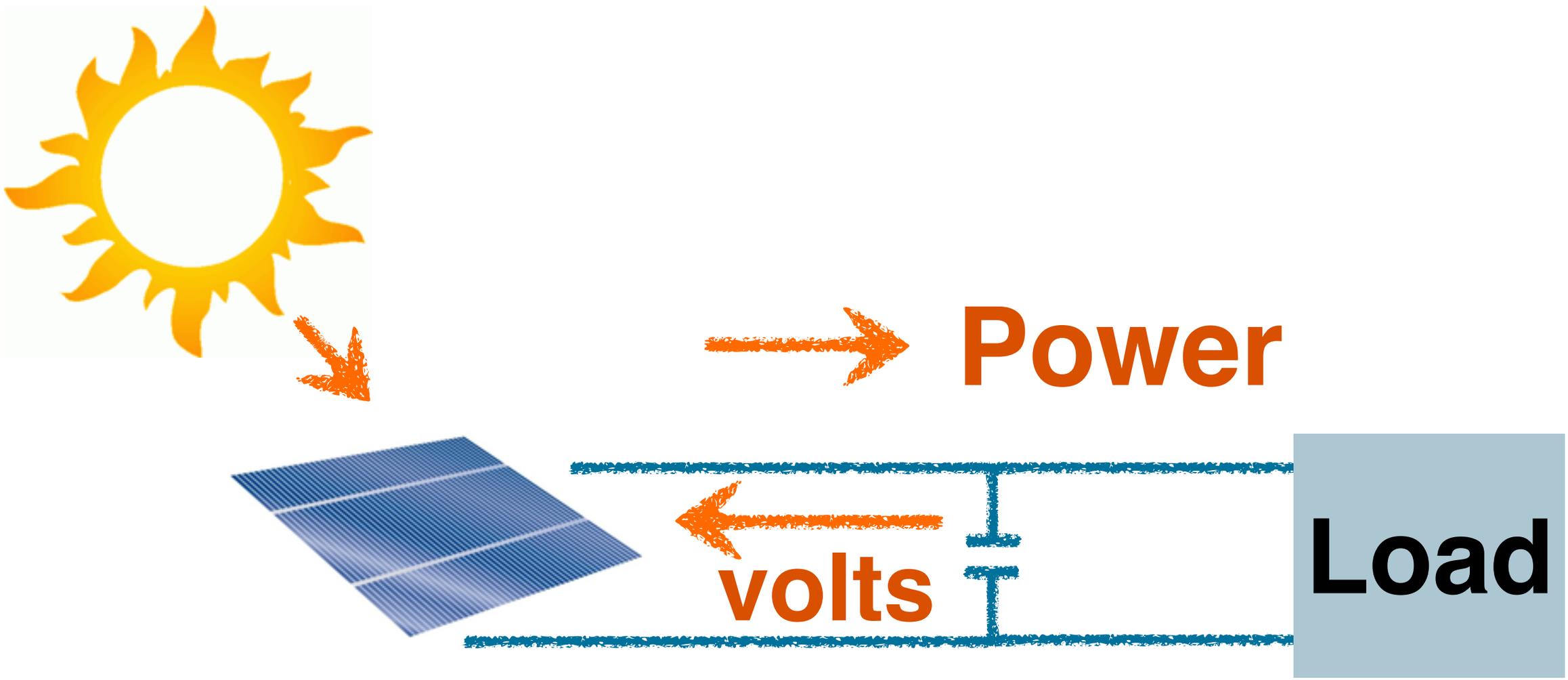

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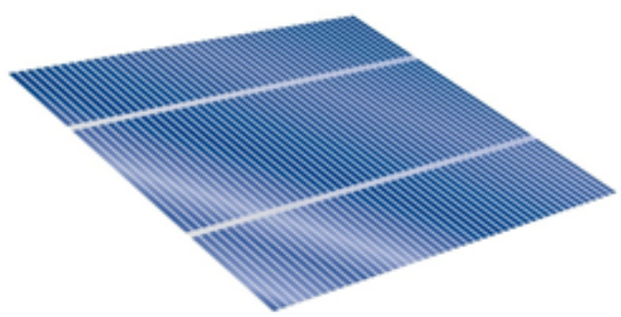
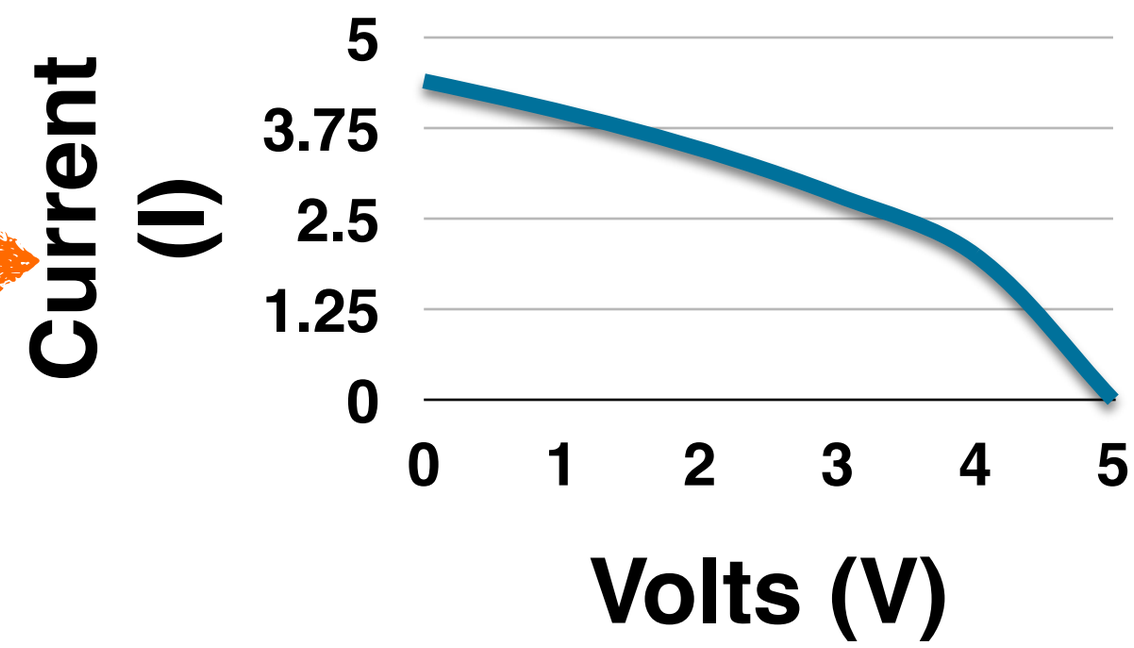
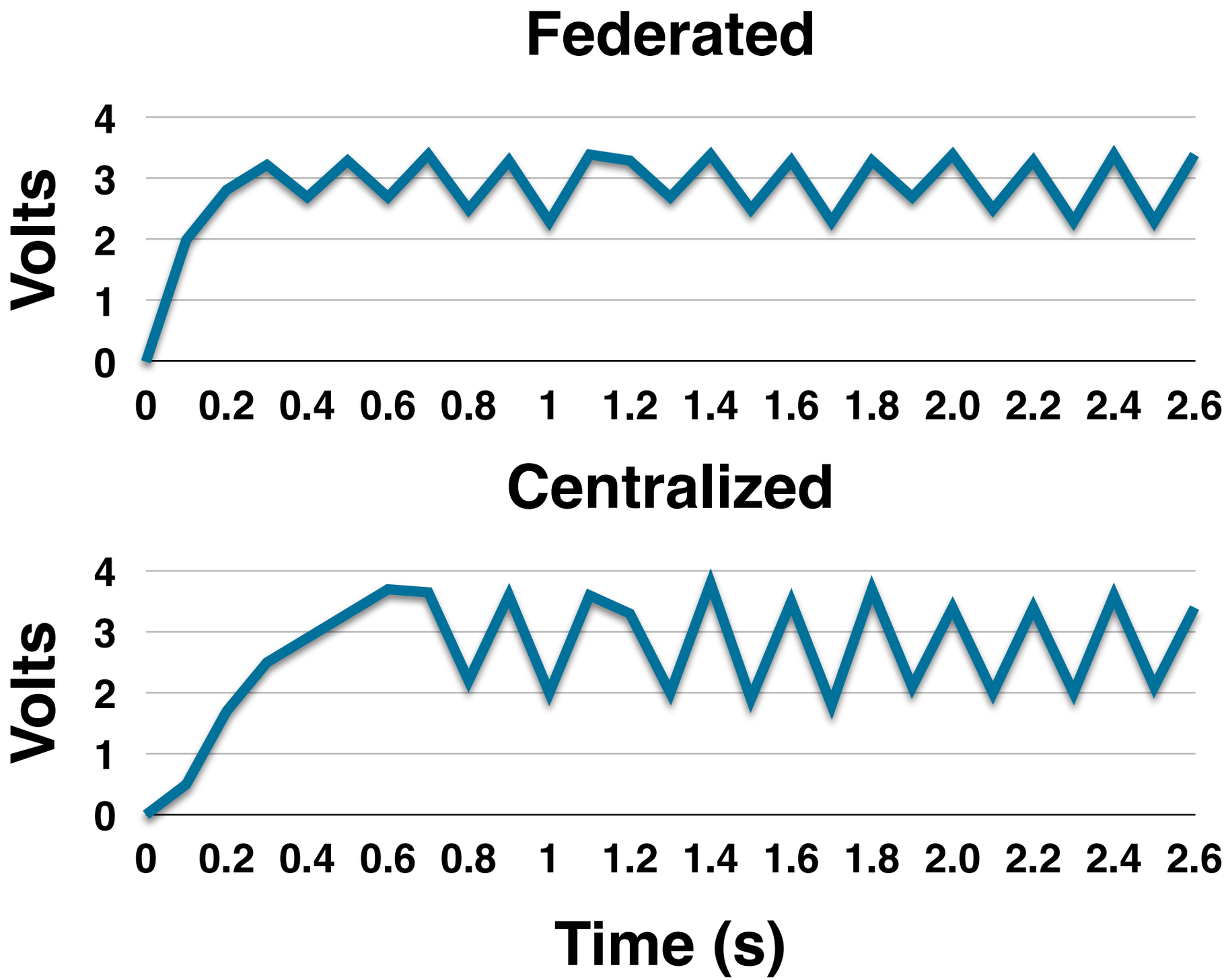


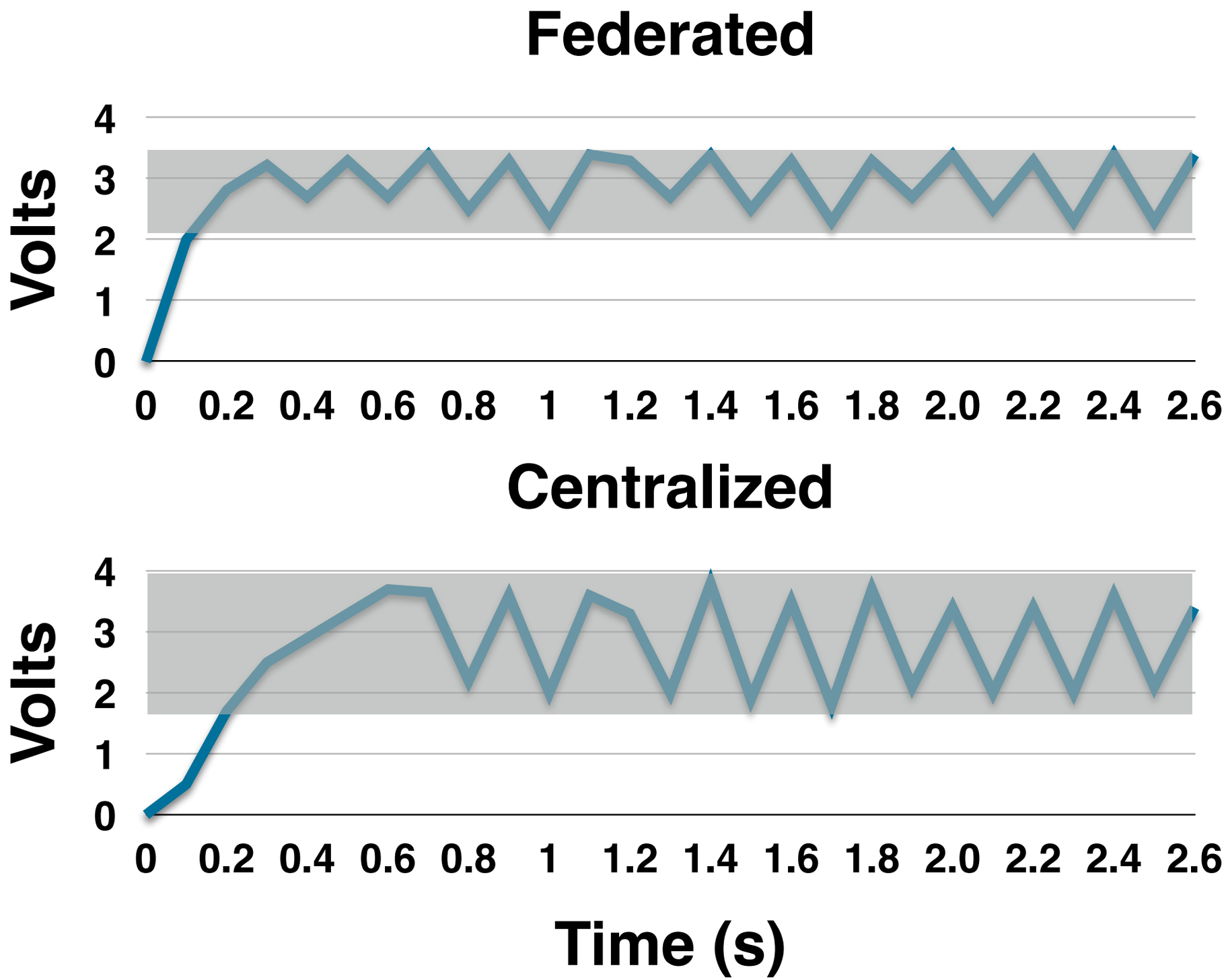


Power, P=IV

Harvest more energy



Harvest more energy



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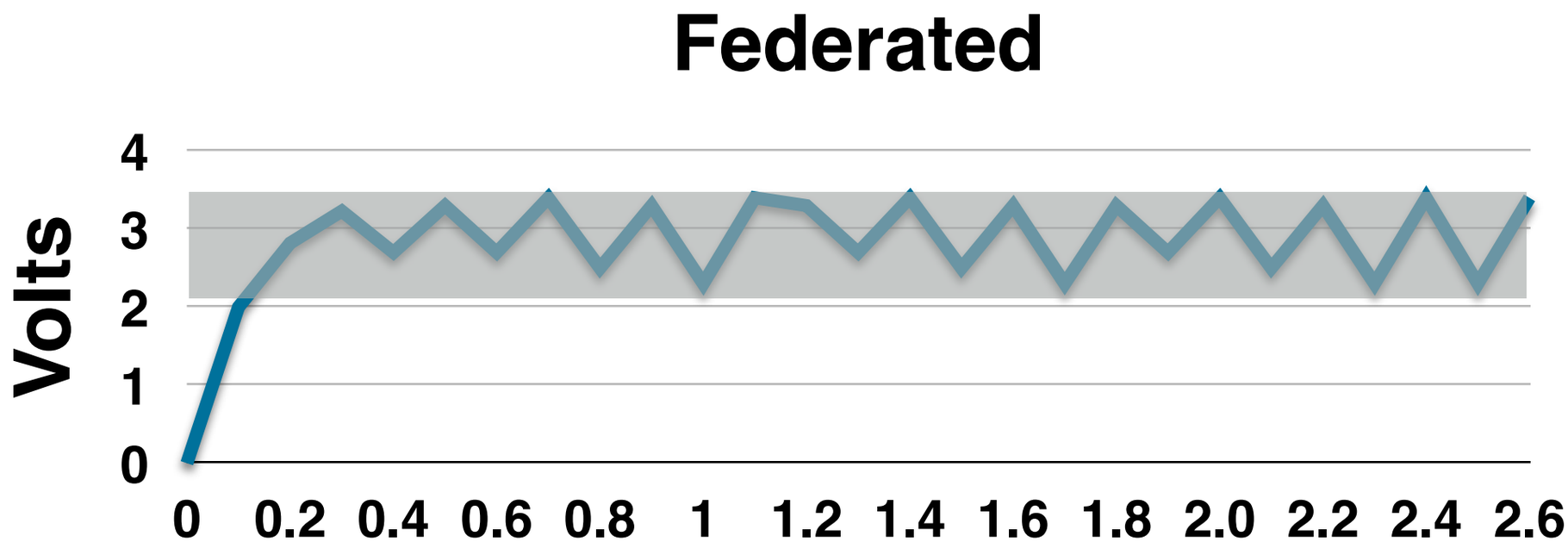
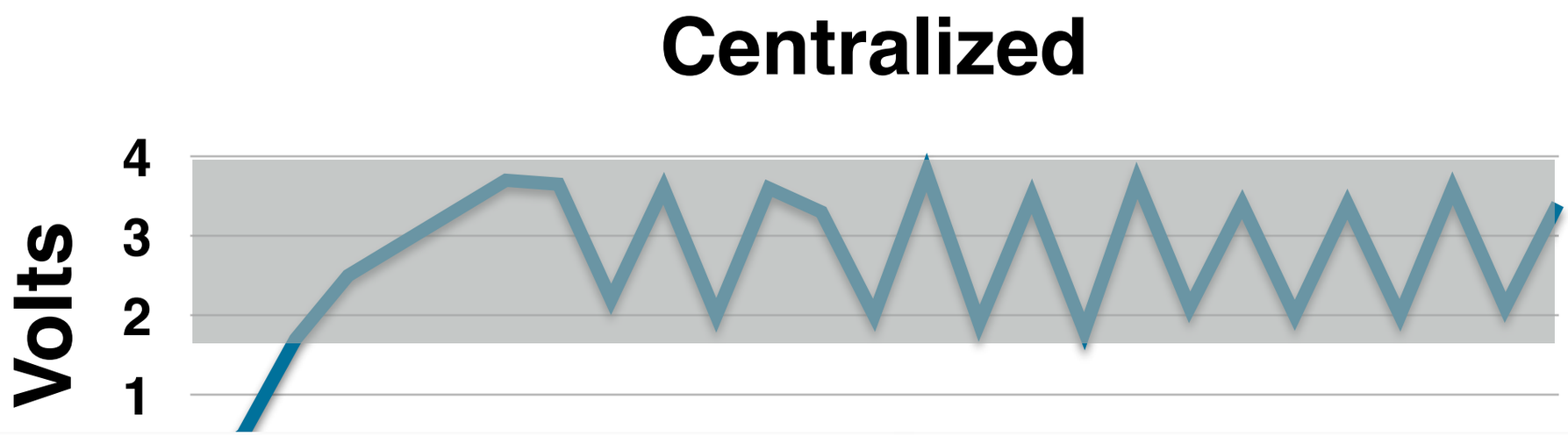
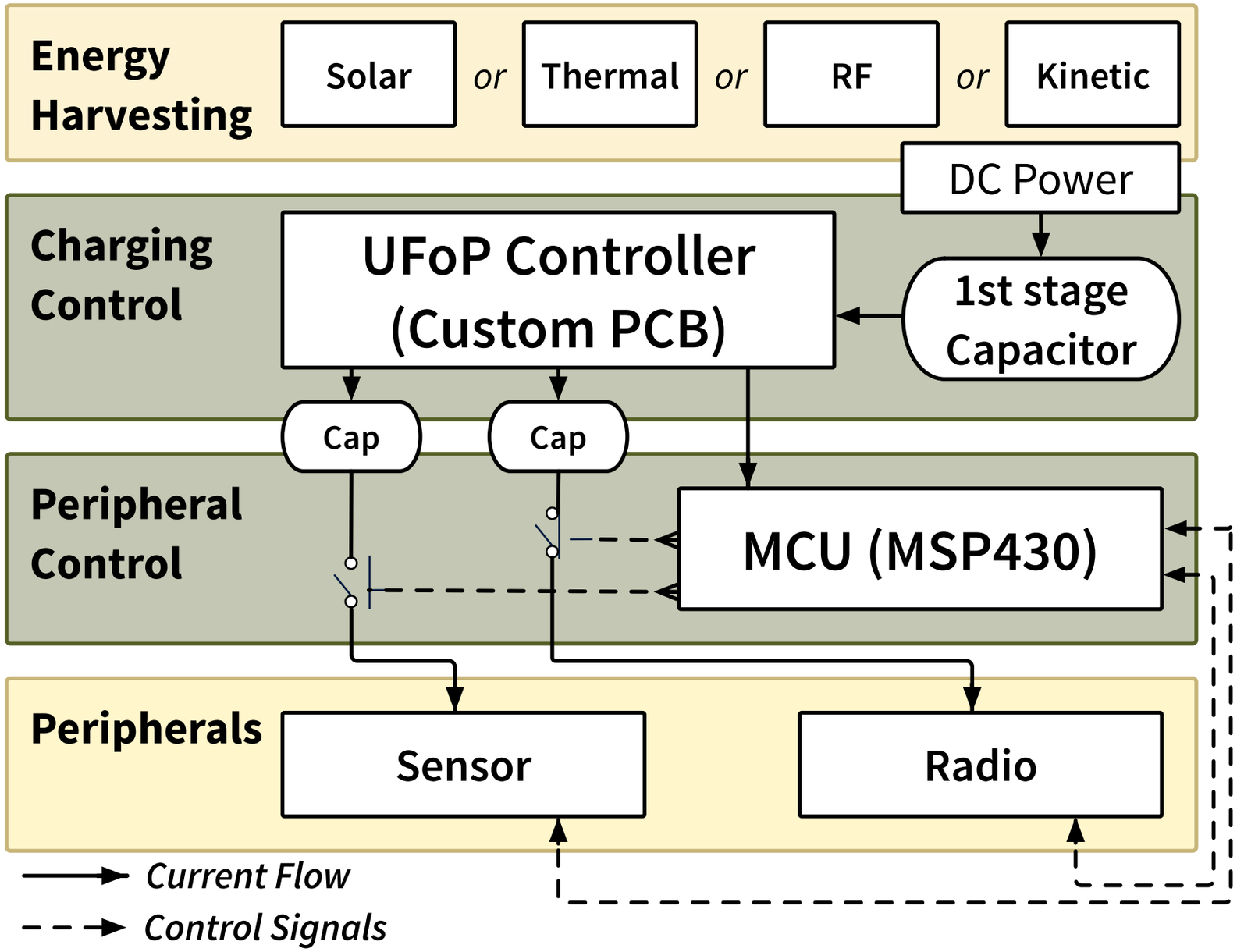


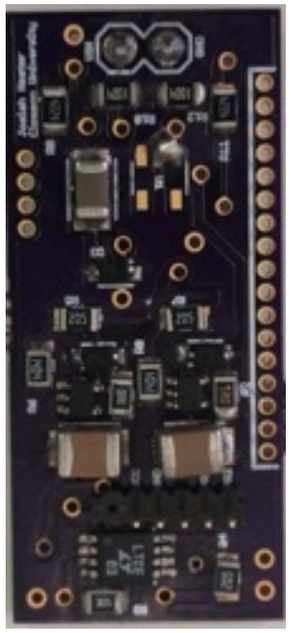


Reduces voltage volatility

Implementation



Results



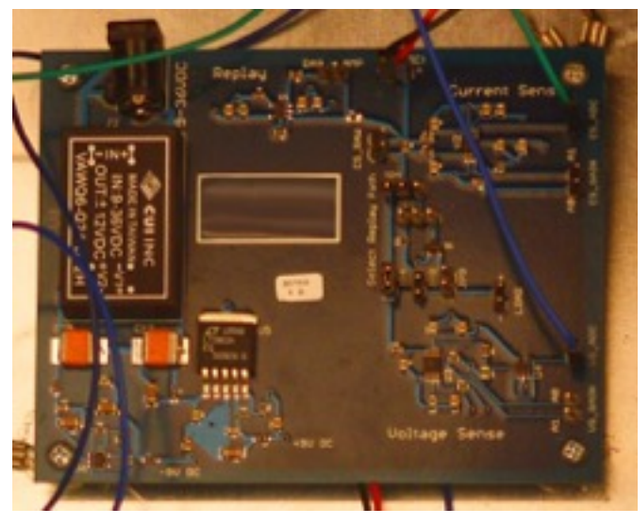
Evaluation

- Availability
- Resiliency
- Energy harvested

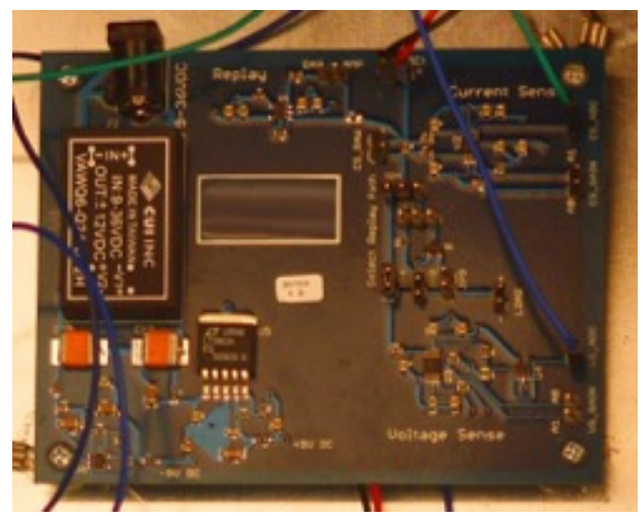
Deployment

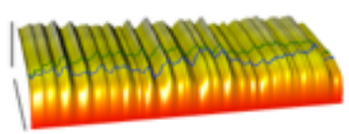
- Greenhouse monitoring

Methodology

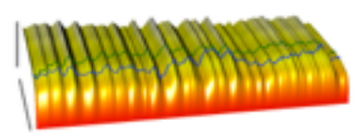


Methodology





RF Low



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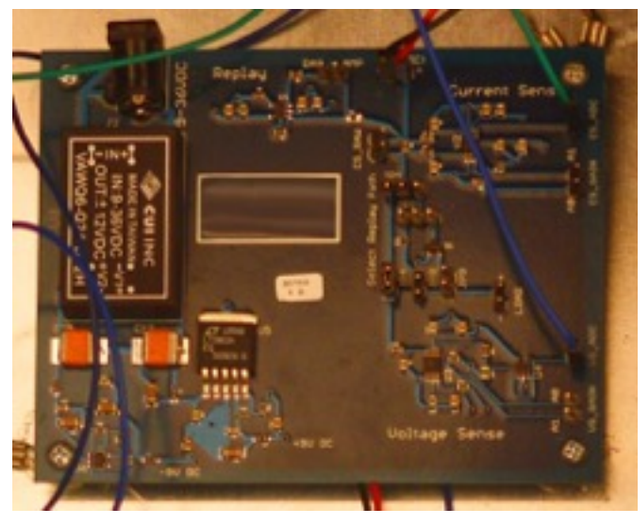
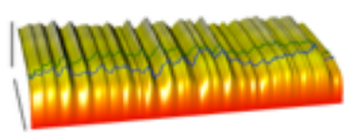
Methodology





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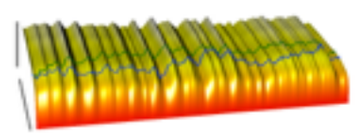
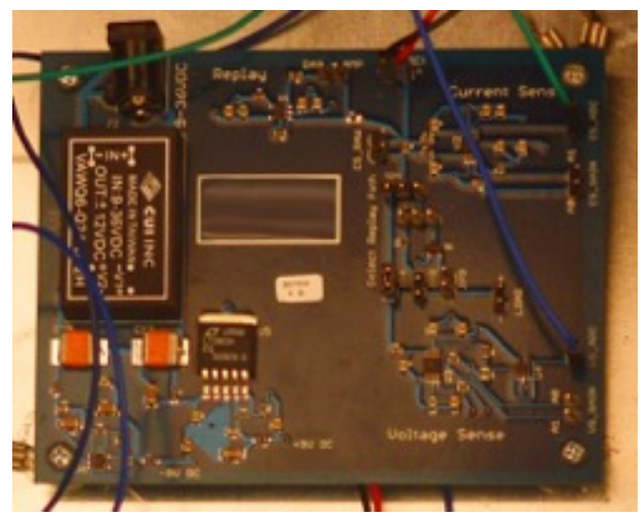
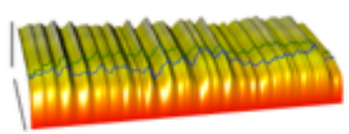


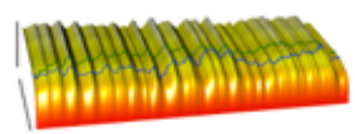
RF High

Methodology

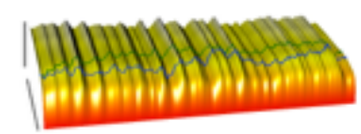




RF Low

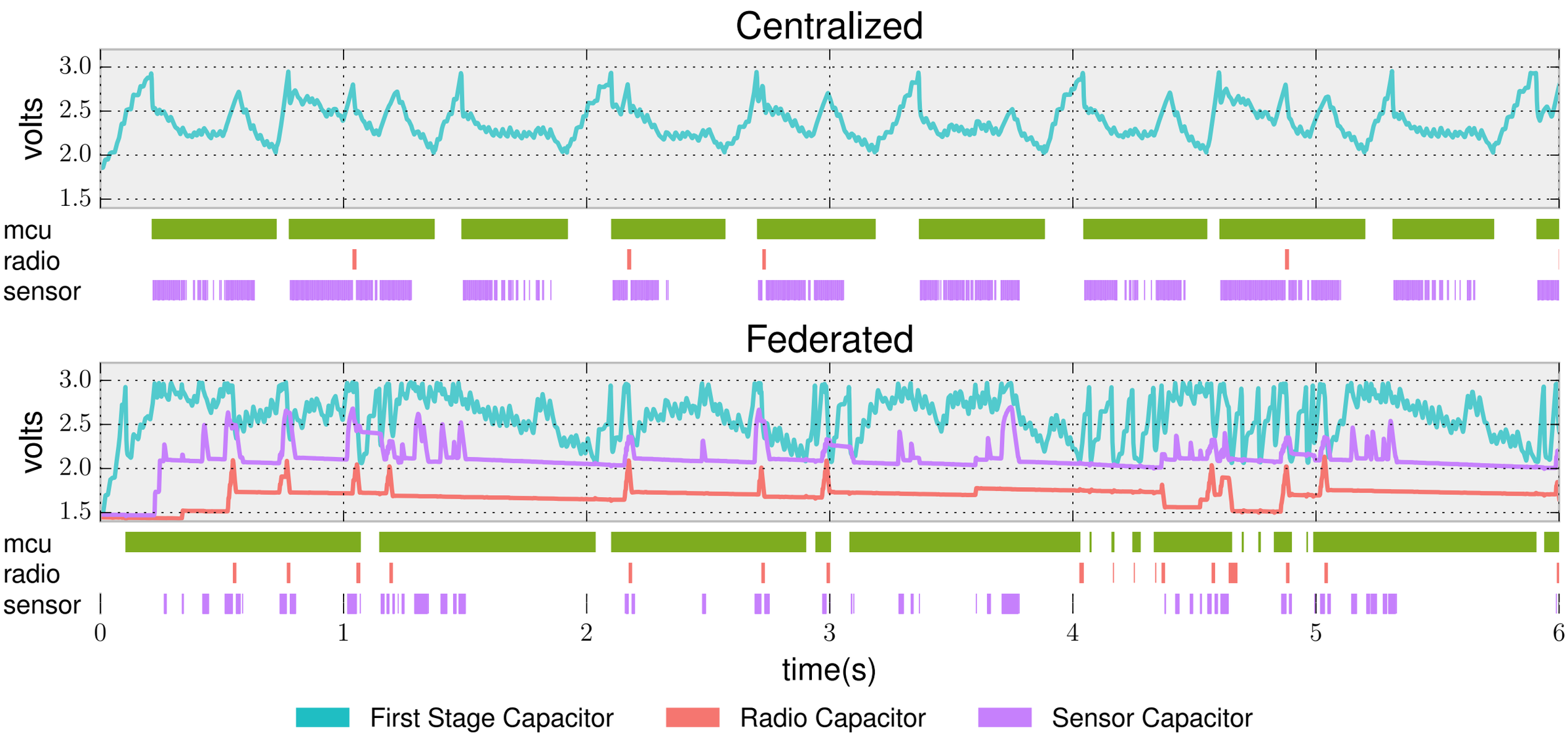


RF High



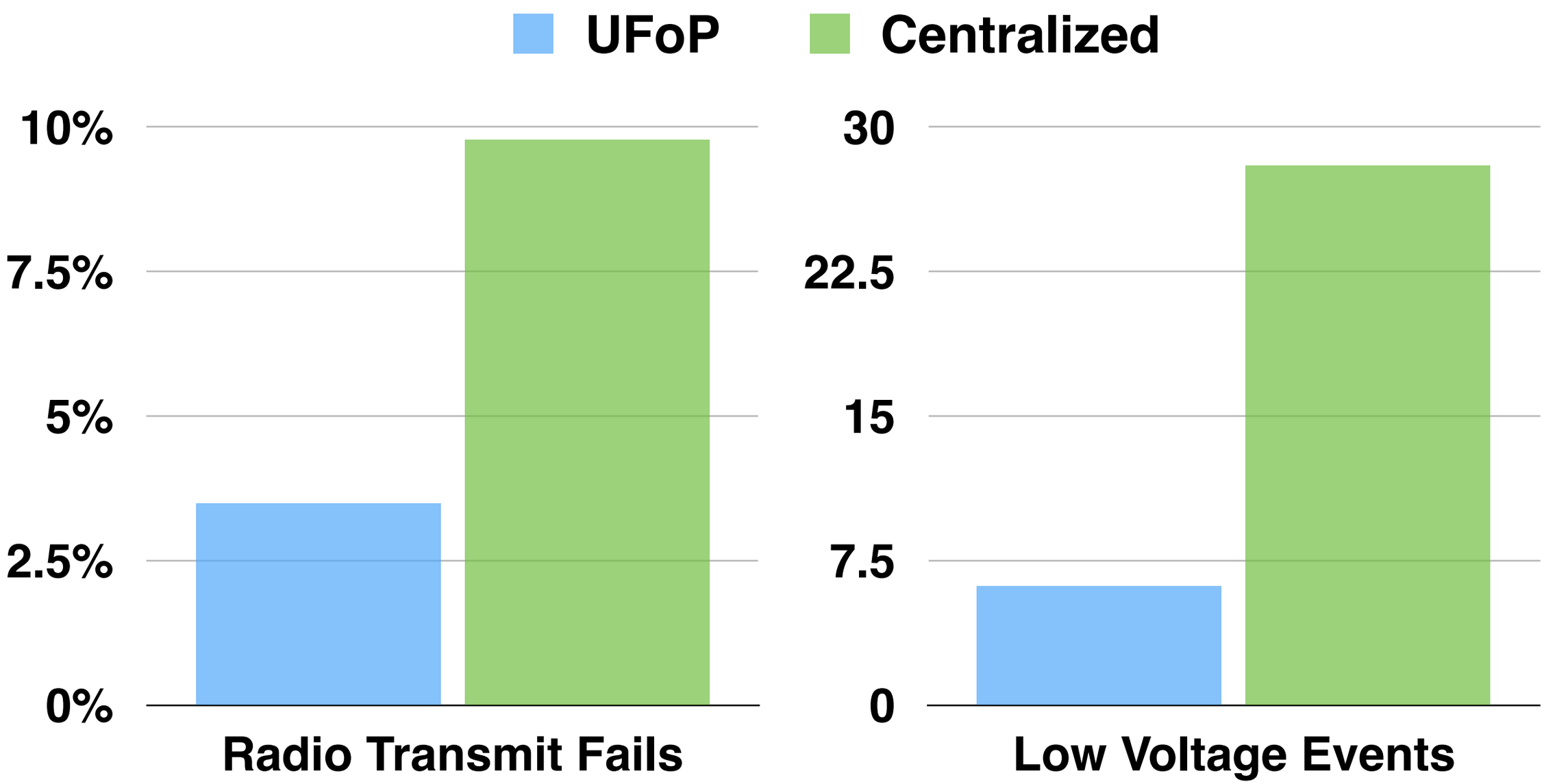
Solar

Availability



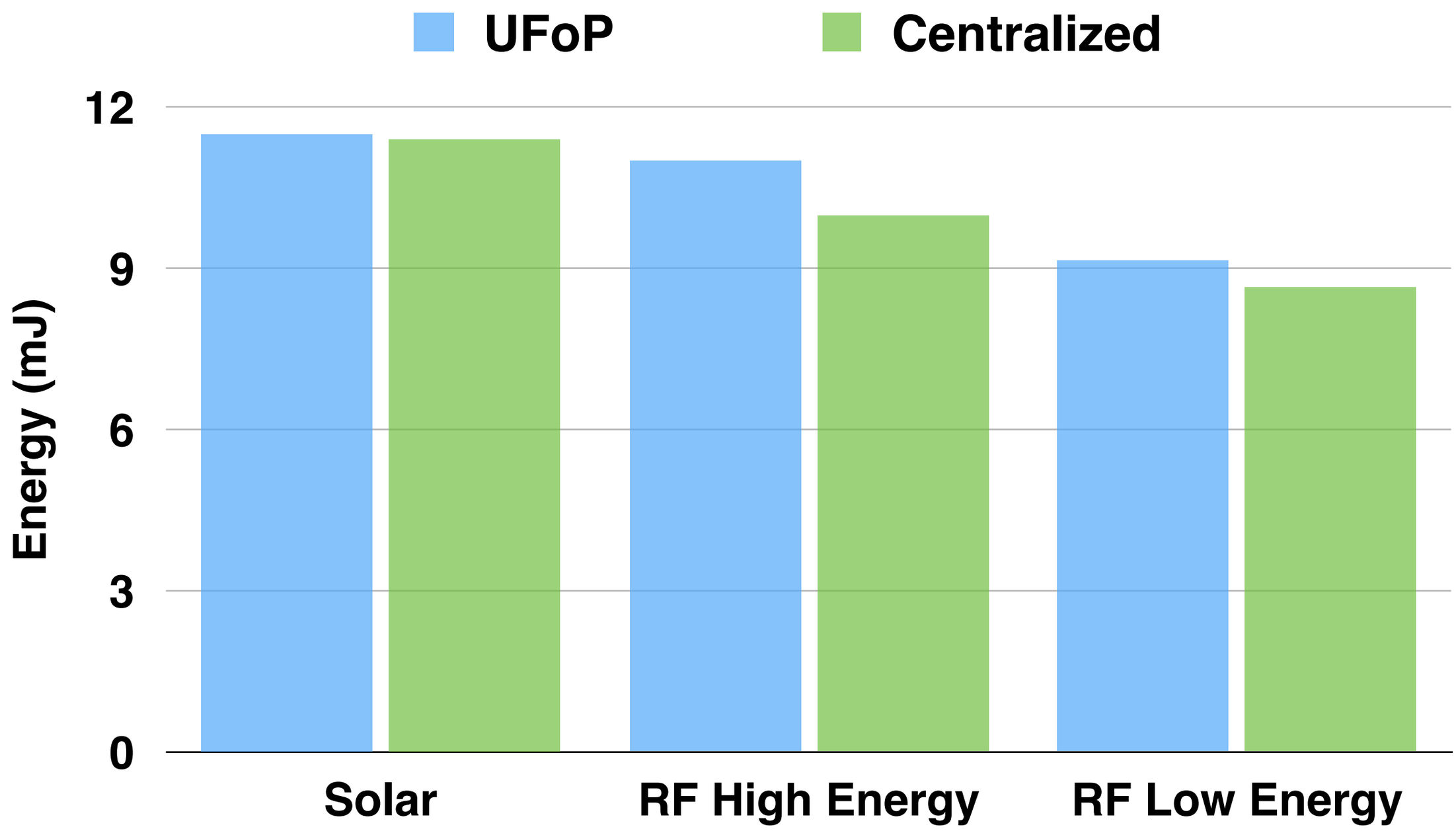
More computational availability

Resiliency



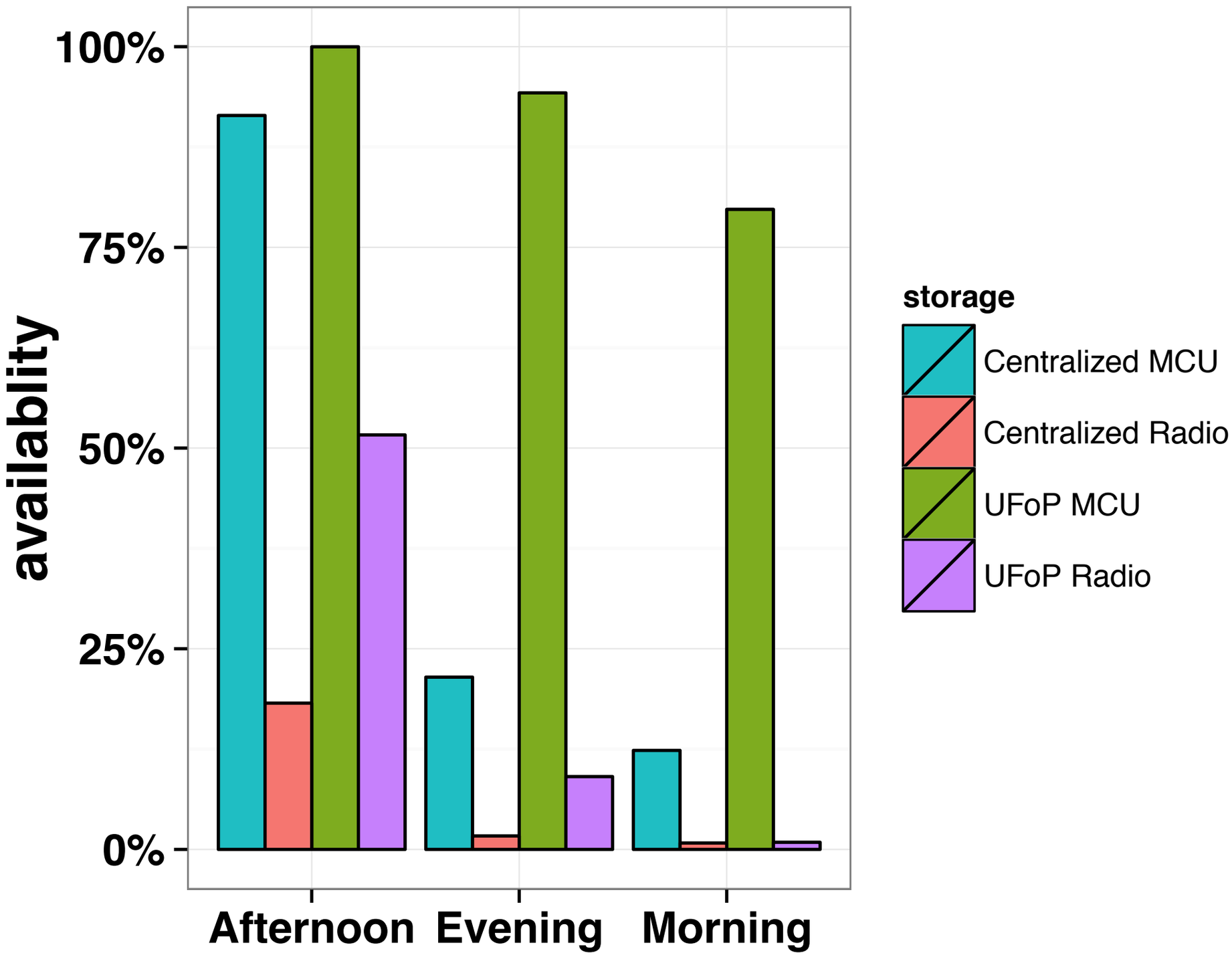
More resilient than without federating

Energy Harvested



More energy harvested

Deployment


availability
100%
75%
50%
25%
0%
Afternoon
Evening
Morning
storage
Centralized MCU
Centralized Radio
UFoP MCU
UFoP Radio

Future Work

Dynamic UFoP

- Dynamic priority, capacity, thresholds
- Resiliency
- Energy harvested

Language

- Manage energy and time

Summary

Federating energy storage dramatically improves the utility of batteryless sensors.

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