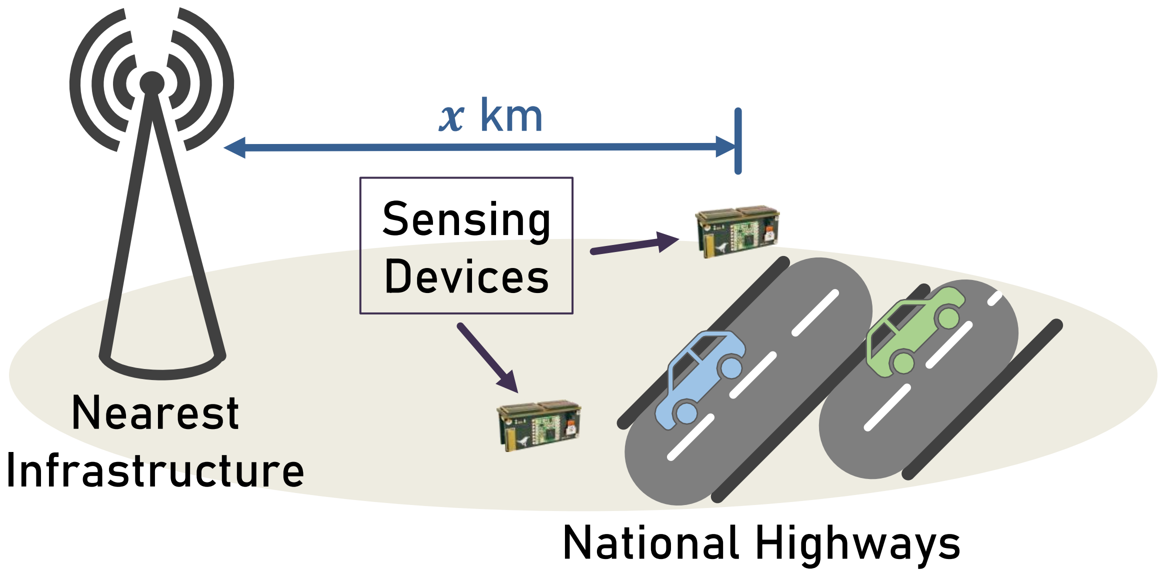
18613: Future of Computing

Part 1: Camaroptera
A Batteryless, Long-Range Camera

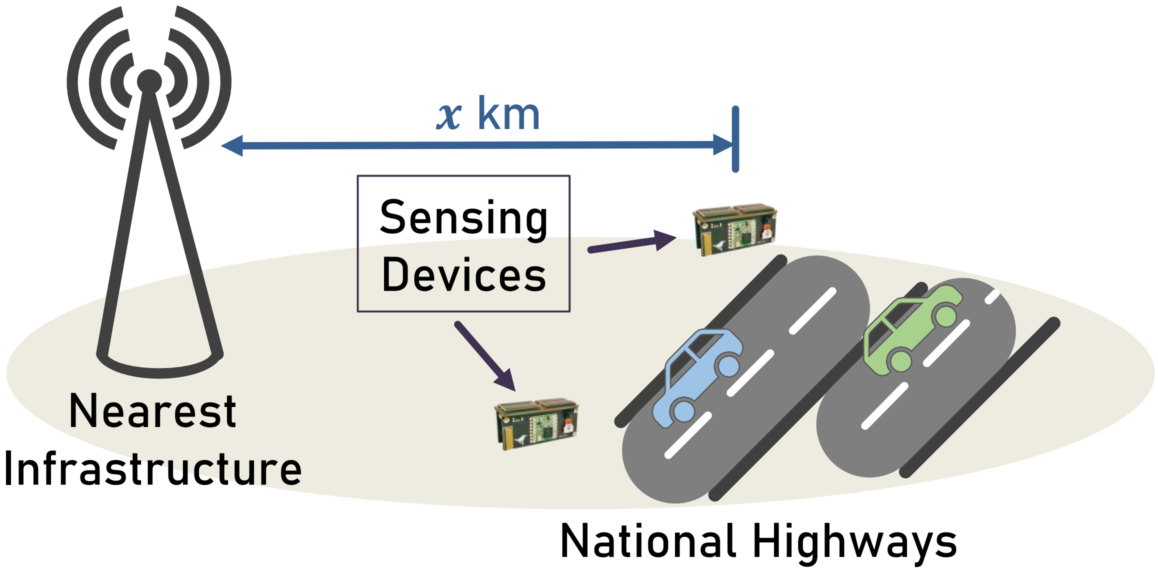
Contents

Contents

Motivation – Remote Sensing Applications

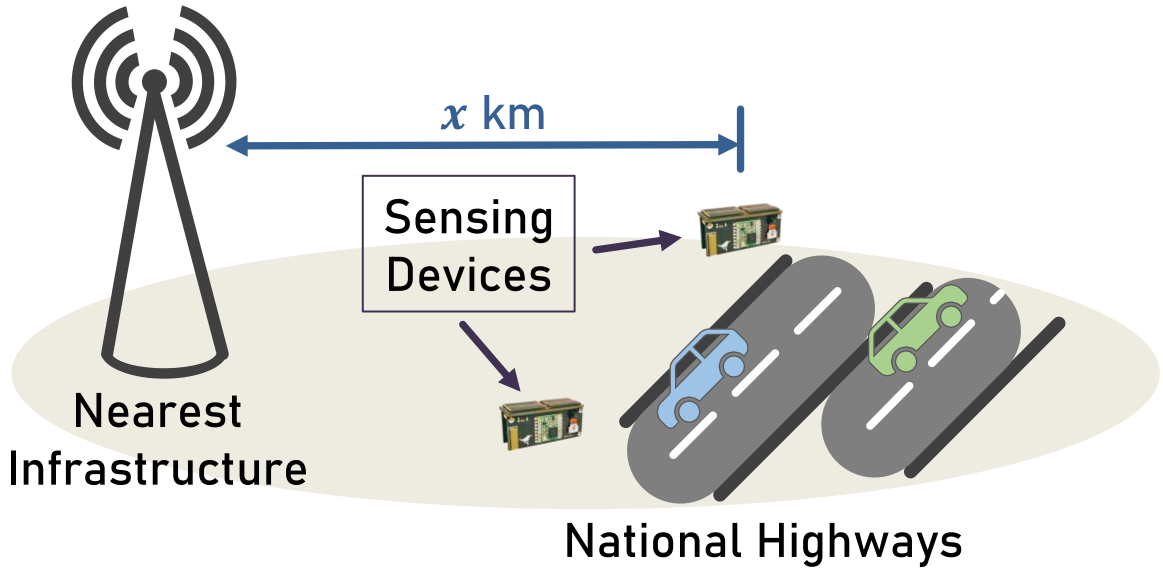


Requirements for Remote Sensing Applications



Requirement 1: Kilometer-range communication

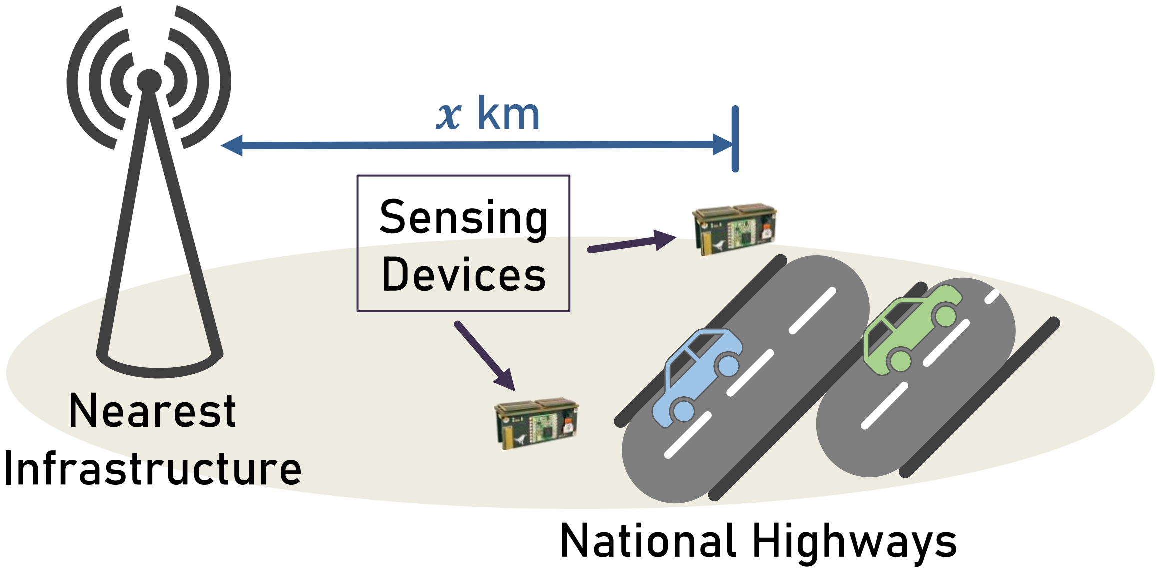
Requirements for Remote Sensing Applications



Requirement 1: Kilometer-range communication

Requirement 2: Maintenance-Free Long Lifetimes

Requirements for Remote Sensing Applications

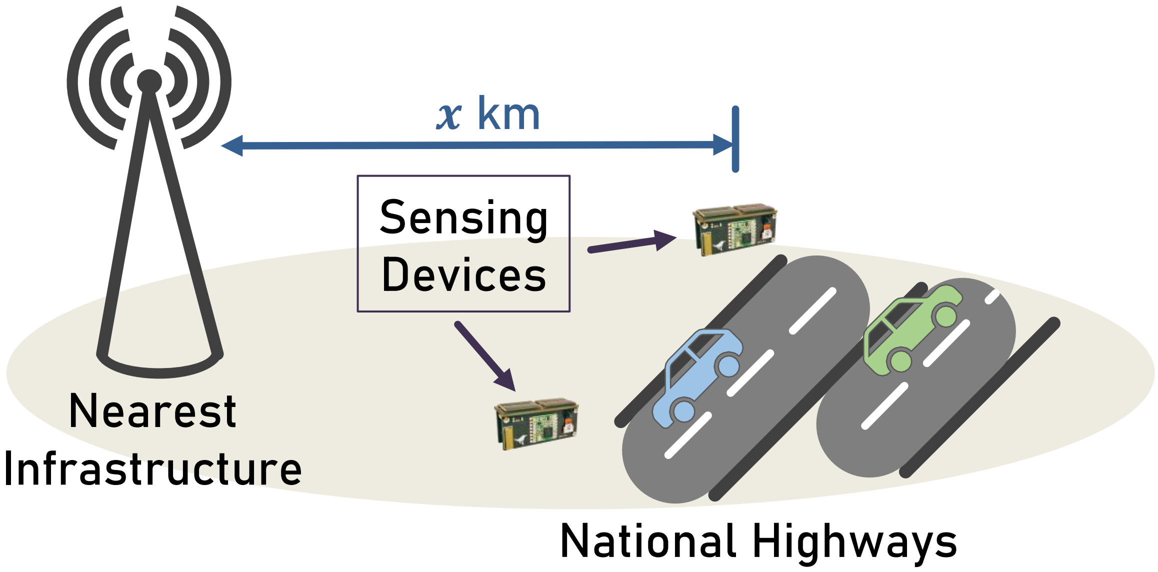


Requirement 1: Kilometer-range communication

Requirement 2: Maintenance-Free Long Lifetimes

Requirement 3: Support Different Applications

Requirements for Remote Sensing Applications



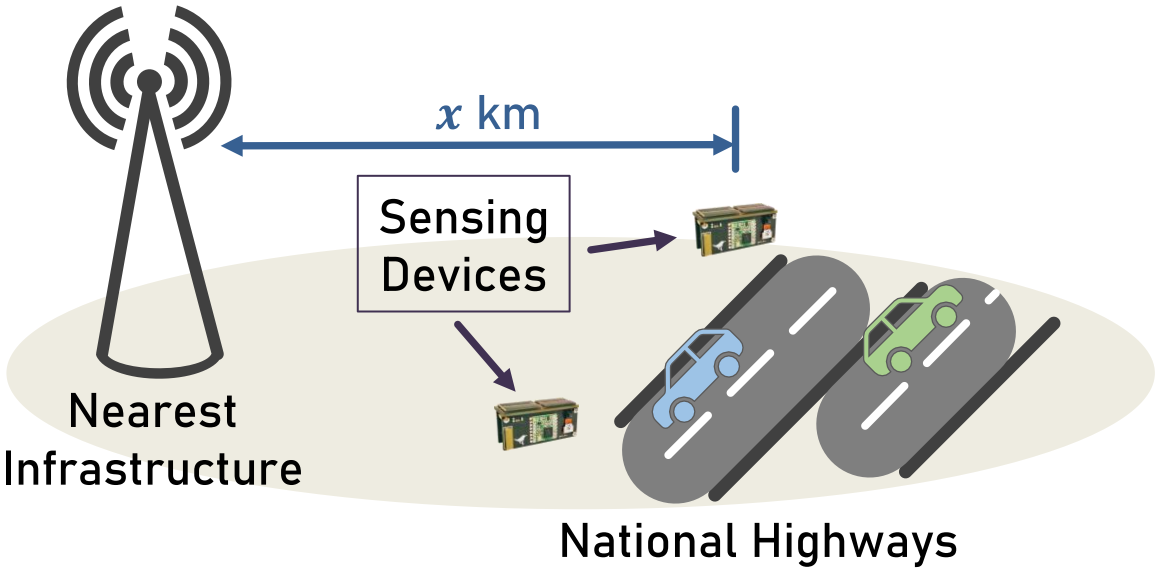
Requirement 1: Kilometer-range communication

Solution: LoRa (kms-range, low-power)

Requirement 2: Maintenance-Free Long Lifetimes

Requirement 3: Support Different Applications

Requirements for Remote Sensing Applications



Requirement 1: Kilometer-range communication

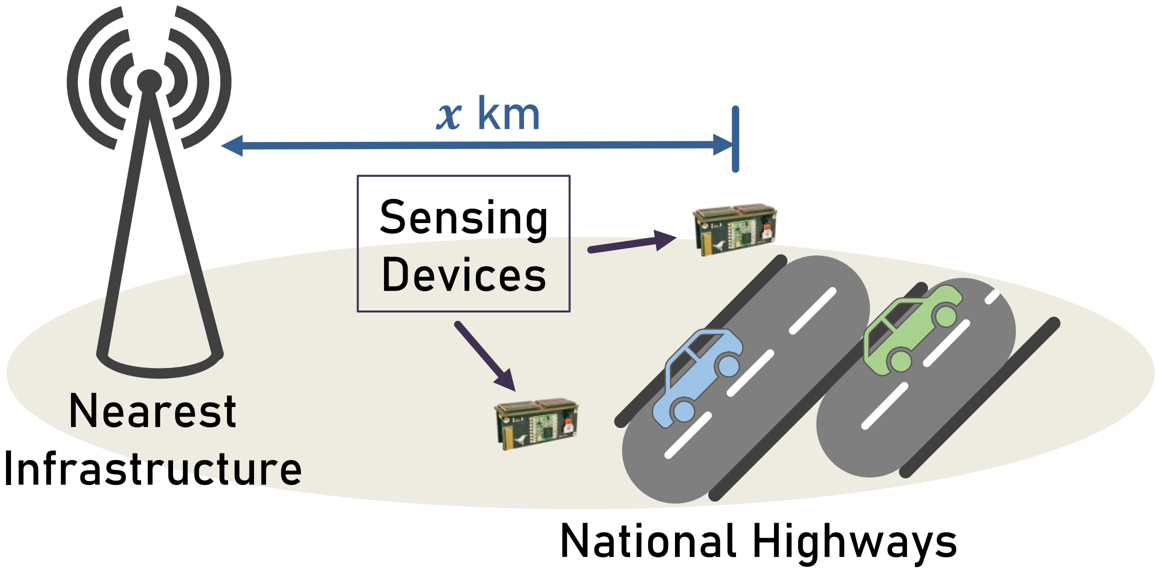
Solution: LoRa (kms-range, low-power)

Requirement 2: Maintenance-Free Long Lifetimes

Solution: Batteryless Operation

Requirement 3: Support Different Applications

Requirements for Remote Sensing Applications



Requirement 1: Kilometer-range communication

Solution: LoRa (kms-range, low-power)

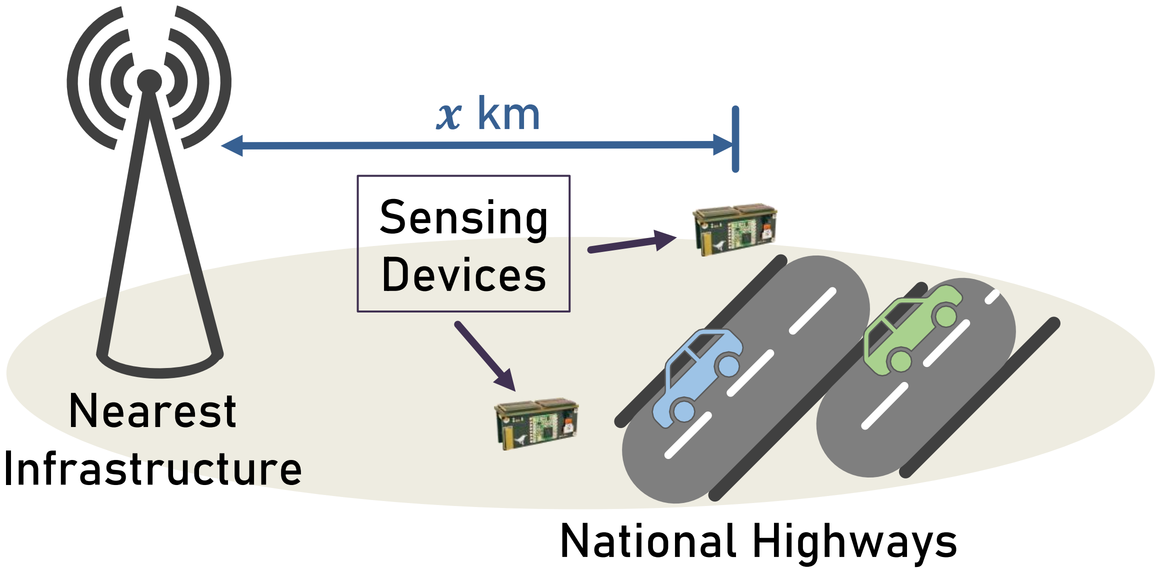
Requirement 2: Maintenance-Free Long Lifetimes

Solution: Batteryless Operation

Requirement 3: Support Different Applications

Solution: Image Sensing

Requirements for Remote Sensing Applications



Requirement 1: Kilometer-range communication

Solution: LoRa (kms-range, low-power)

Requirement 2: Maintenance-Free Long Lifetimes

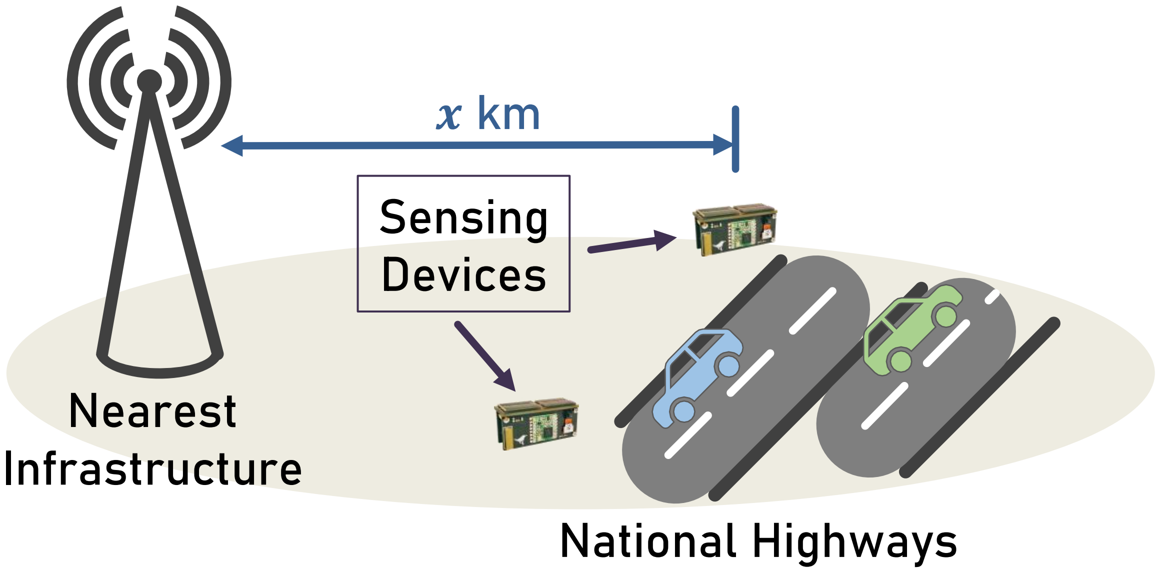
Solution: Batteryless Operation

Requirement 3: Support Different Applications

Solution: Image Sensing

Challenge: Image Communication over kms is costly

Requirements for Remote Sensing Applications



Requirement 1: Kilometer-range communication

Solution: LoRa (kms-range, low-power)

Requirement 2: Maintenance-Free Long Lifetimes

Solution: Batteryless Operation

Requirement 3: Support Different Applications

Solution: Image Sensing

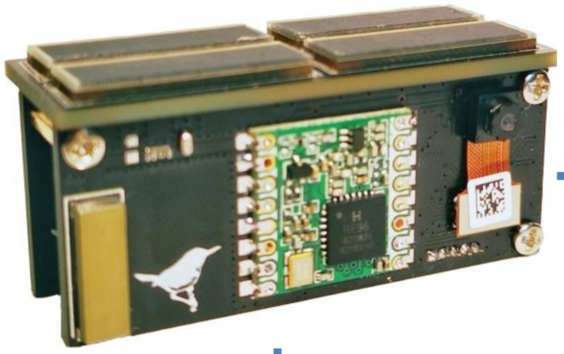
Challenge: Image Communication over kms is costly

Solution: Local, On-Device Computing

Contents

- Motivation – Remote Sensing Applications
- Camaroptera Design
- Experimental Results
- Future Directions

Hardware Design



Sensing & Communication

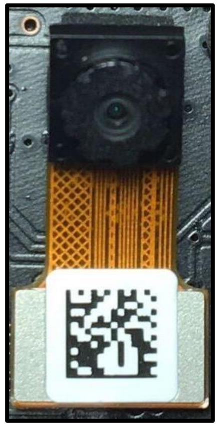
Processing

Energy Harvesting

Sensing & Communication

Camera Sensor – Himax HM01B0

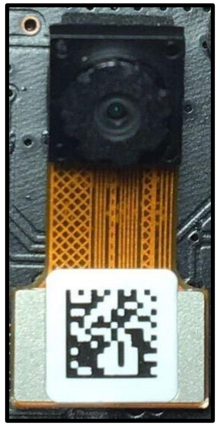
- Ultra-low power image sensor
  ~1.1mW @QQVGA
- Camaroptera Resolution
  QQVGA – 160 x 120
  suffices for machine inference



Sensing & Communication

Camera Sensor – Himax HM01B0

- Ultra-low power image sensor
  ~1.1mW @QQVGA
- Camaroptera Resolution
  QQVGA – 160 x 120
  suffices for machine inference



LoRa Radio – RFM95W

- Cheap, low-energy radio with range in kilometer(s)
- Permits pervasive deployment

Processing

Microcontroller – Texas Instruments MSP430FR5994

- Ultra-low power 16-bit microcontroller:
  - Clock – upto 16MHz
  - Memory – 256kB FRAM
  - Power consumption - ~3mW

Energy Harvesting

Solar Panels

- 22mm x 7mm x 1.8mm

- V_{MPP} = 3.4V
- I_{MPP} = 3.8mA

Camaroptera:
Four in parallel

Energy Harvesting

Solar Panels

- 22mm x 7mm x 1.8mm

- V_{MPP} = 3.4V
- I_{MPP} = 3.8mA

Camaroptera:
Four in parallel

Super Capacitor

- 20mm x 15mm x 3.5mm

- C = 33mF
- V_{RATED} = 5.5V

Energy Harvesting

Solar Panels

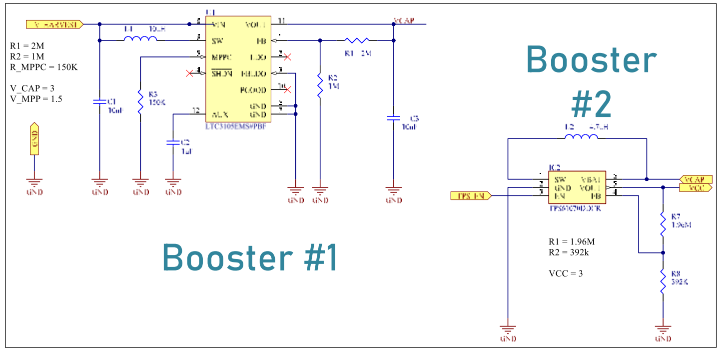
- 22mm x 7mm x 1.8mm
- V_{MPP} = 3.4V
- I_{MPP} = 3.8mA

Camaroptera:
Four in parallel

Super Capacitor

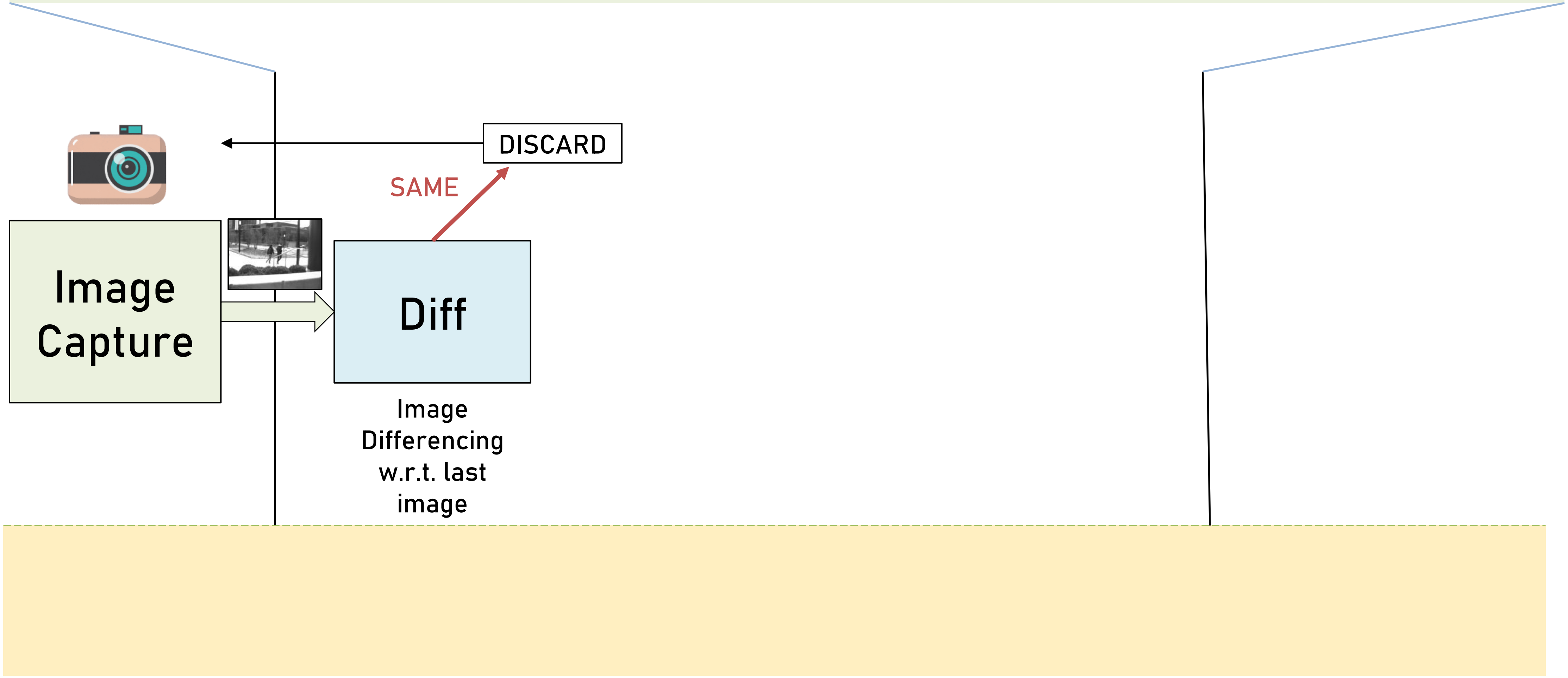
- 20mm x 15mm x 3.5mm
- C = 33mF
- V_{RATED} = 5.5V

Dual Booster Circuit

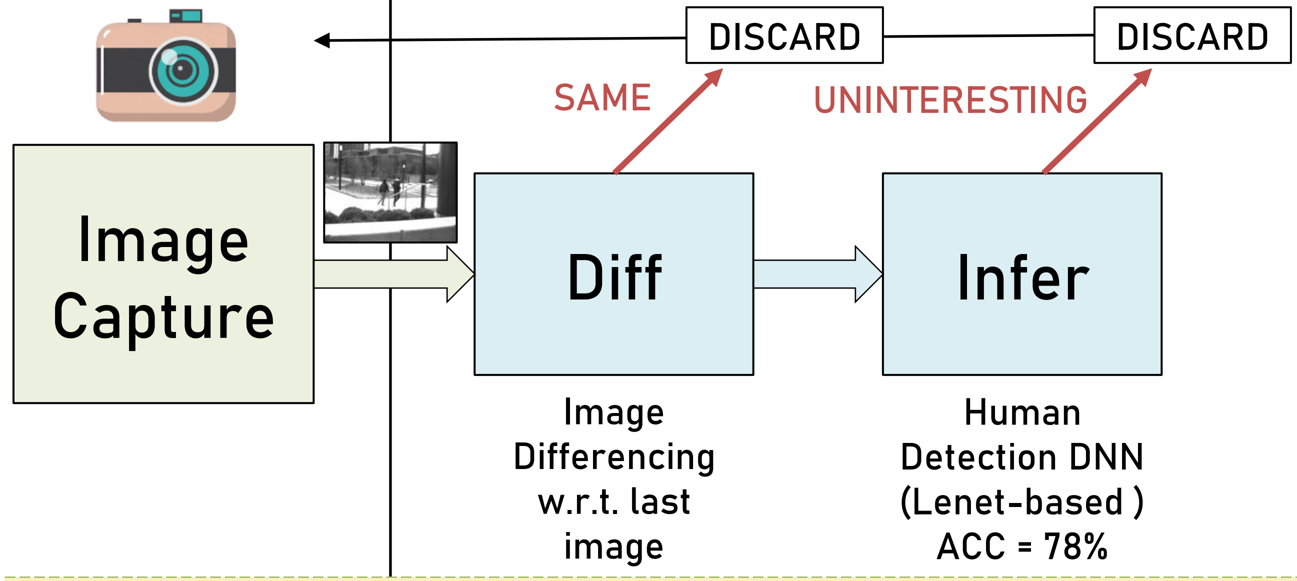


- Input Booster (#1):
  Charge the Super Capacitor
- Output Booster (#2):
  Provide regulated 3V voltage

At-Sensor Processing Pipeline



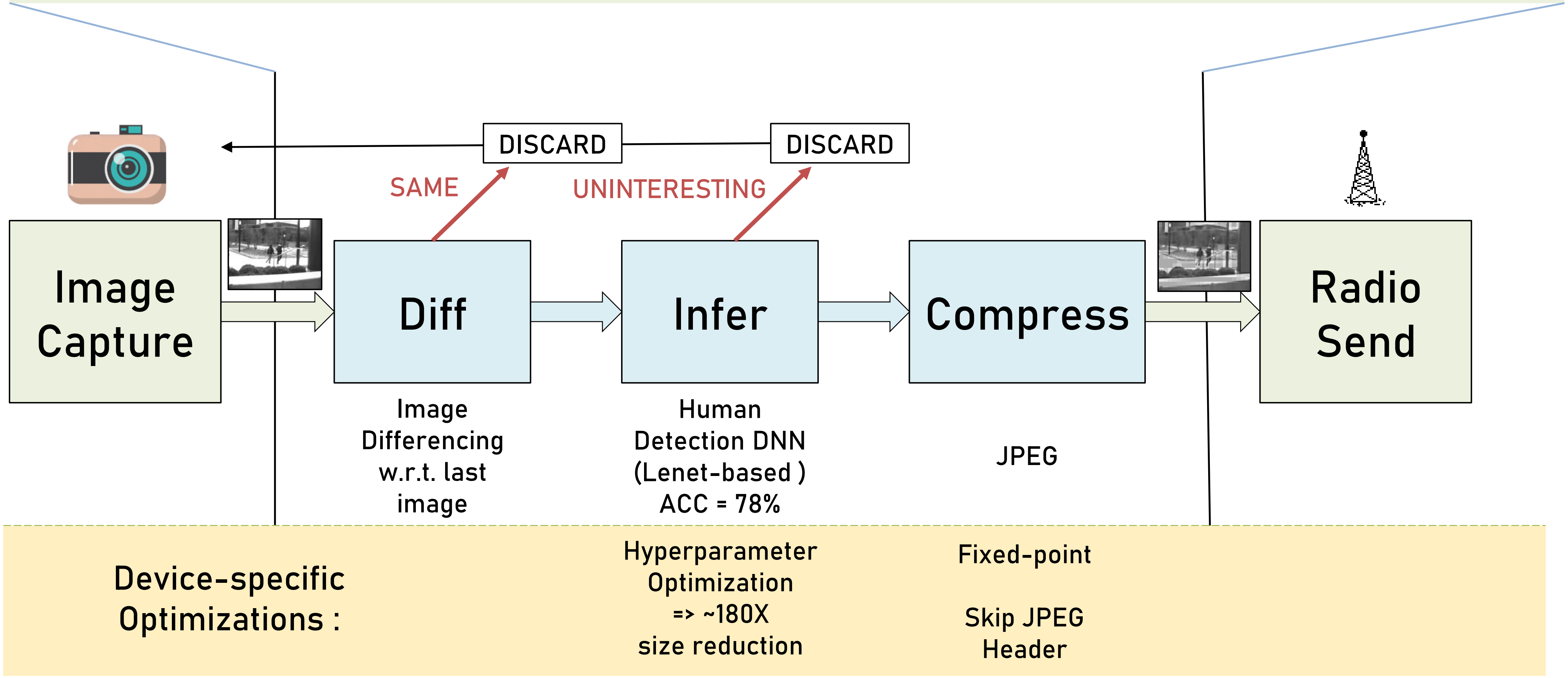
At-Sensor Processing Pipeline



Device-specific Optimizations :

Hyperparameter Optimization => ~180X size reduction

At-Sensor Processing Pipeline

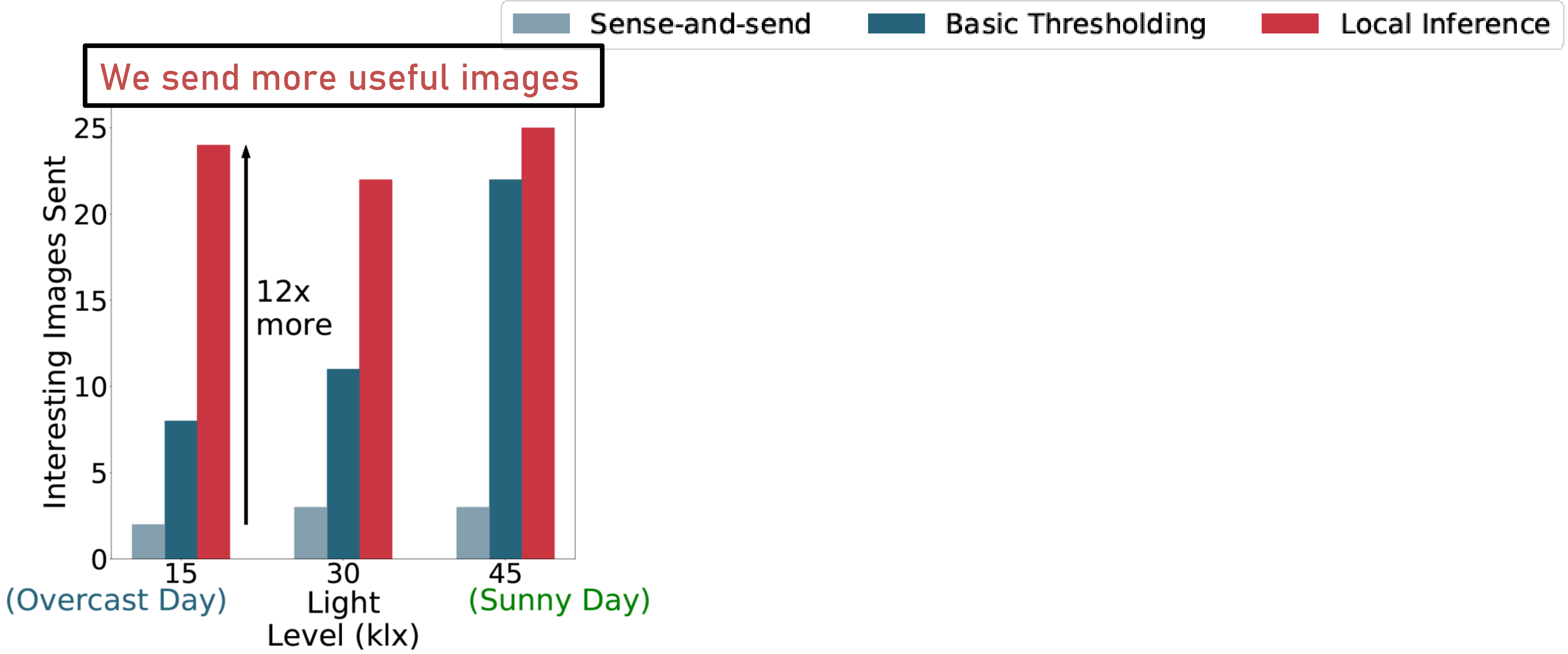


Contents

- Motivation – Remote Sensing Applications
- Camaroptera Design
- Experimental Results
- Future Directions

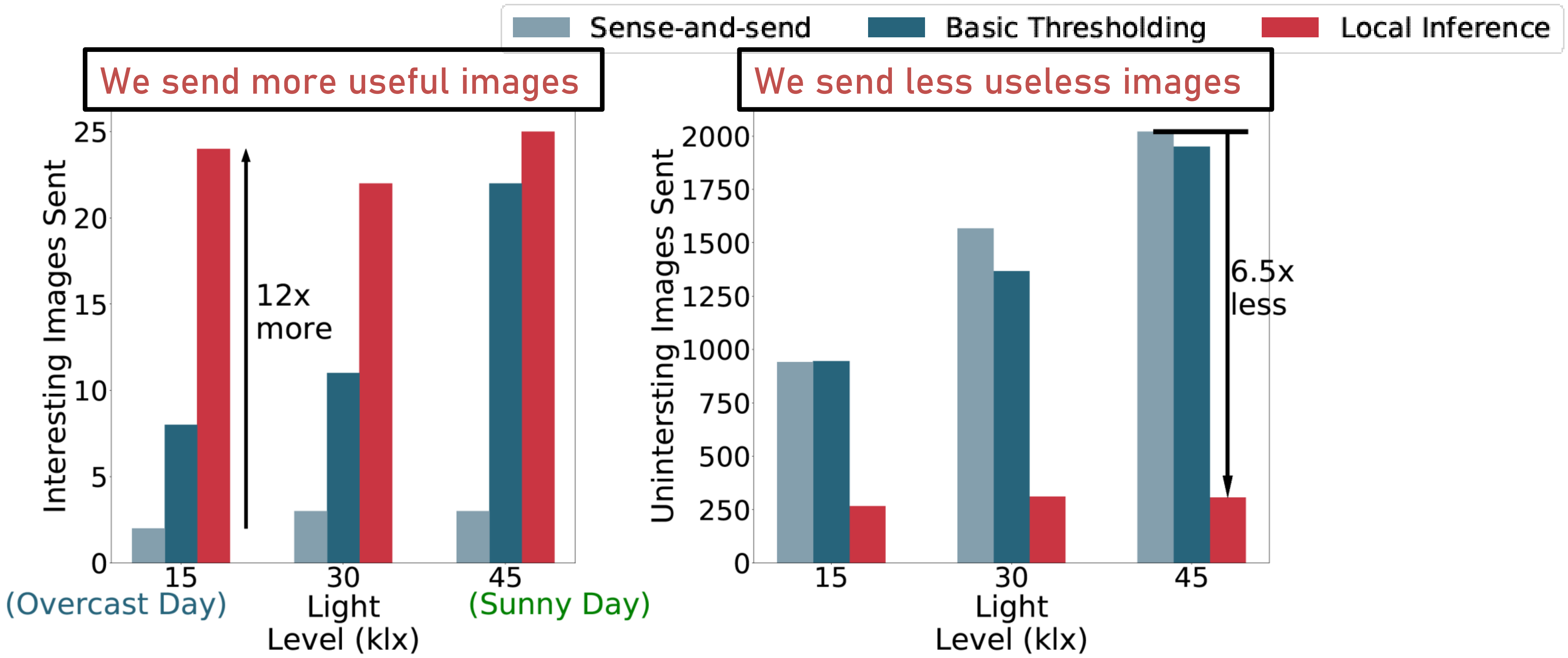
Experimental Results

We send more useful images

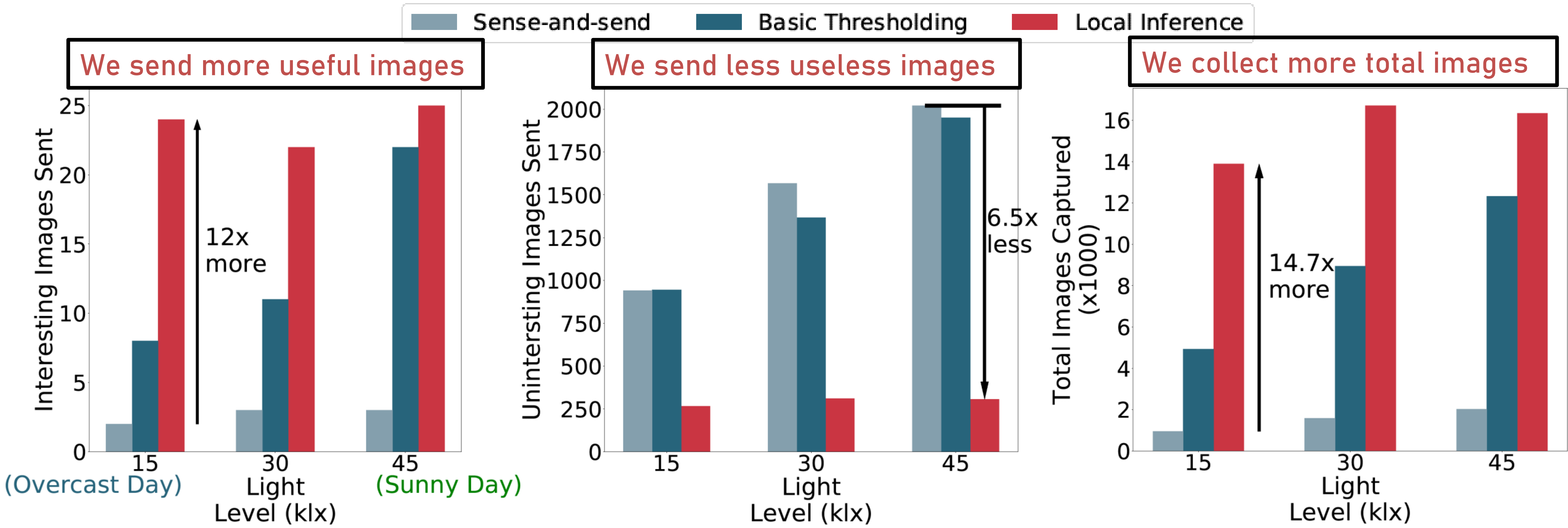


Electrical & Computer ENGINEERING

Experimental Results



Experimental Results



Contents

Future Directions

- Faster computation with new architectures
- Integration with other applications e.g. AR/VR Systems, Stereo Vision, Pose Detection

Summary

- Camaroptera: a batteryless, wireless, long-range image sensor
- Designed for Remote Sensing Applications
- On-device software pipeline

Part 2: How to Run Energy-harvesting Systems Faster

Contents

- The Challenge
- Our Proposal - PHASE

Contents

- The Challenge
- Our Proposal - PHASE

The Challenge

How to run an Energy-harvesting (EH) System faster?

- EH systems derive energy from environments
- Every J spent has to be collected

Time has to be spent on recharging during which the system is inactive

- This recharging time could bottleneck execution, affecting end-to-end performance.

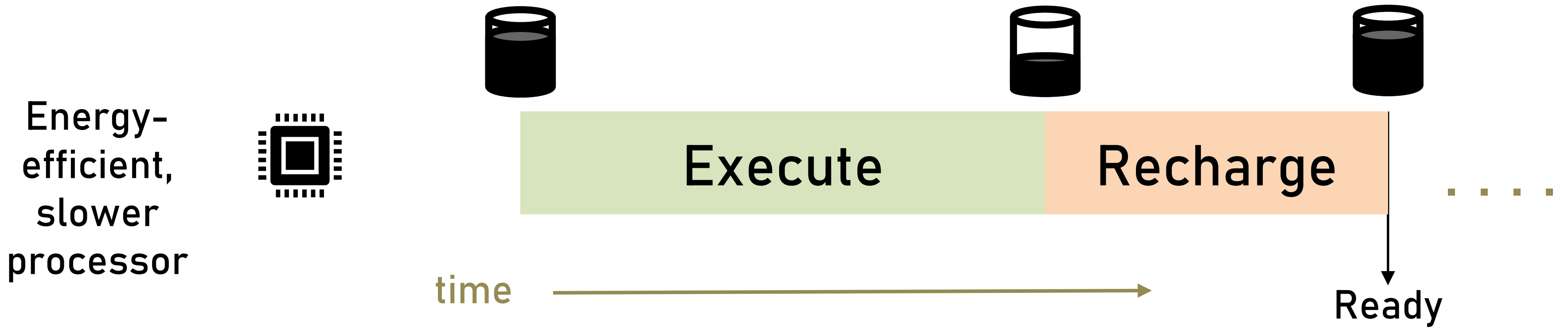
Electrical & Computer ENGINEERING

Performance in Energy Harvesting Systems

Why not simply use a faster processor?

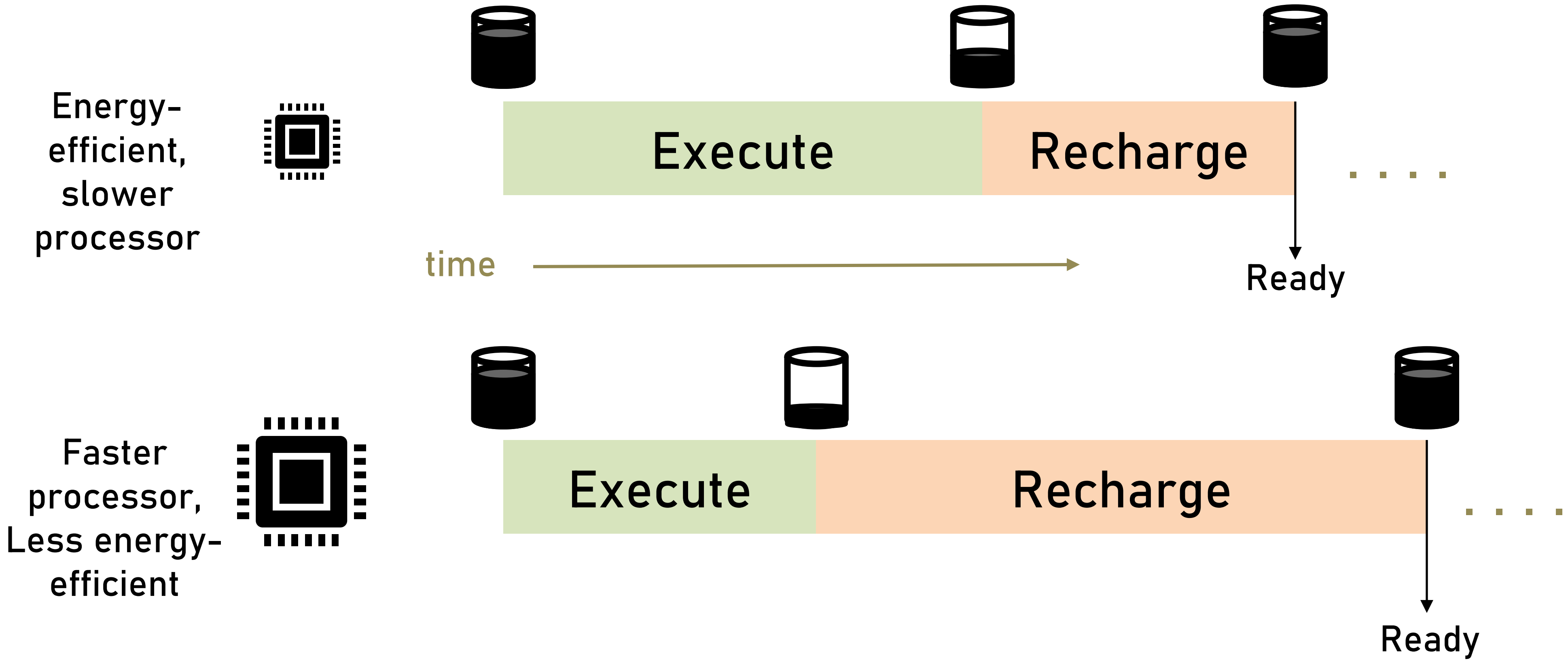
Performance in Energy Harvesting Systems

Why not simply use a faster processor?



Performance in Energy Harvesting Systems

Why not simply use a faster processor?



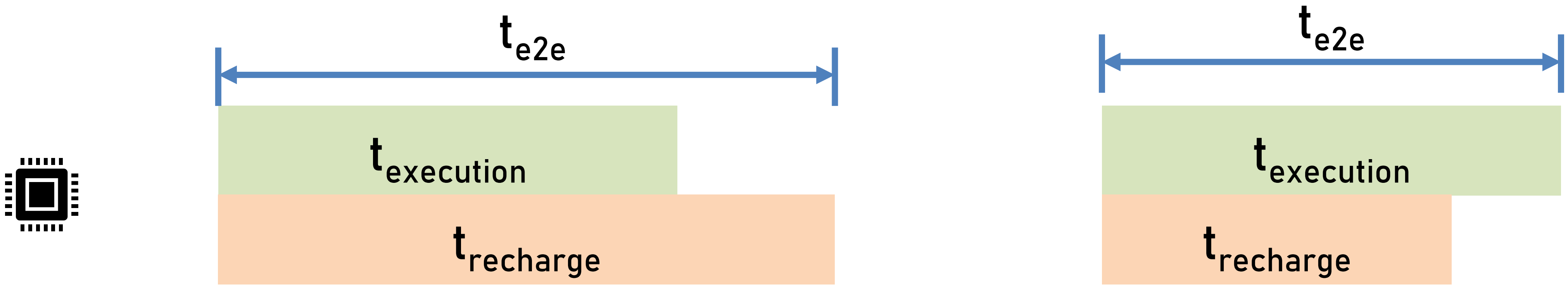
Contents

PHASE

Modeling Performance in Energy-Harvesting Sensors

Time for end-to-end workload latency:

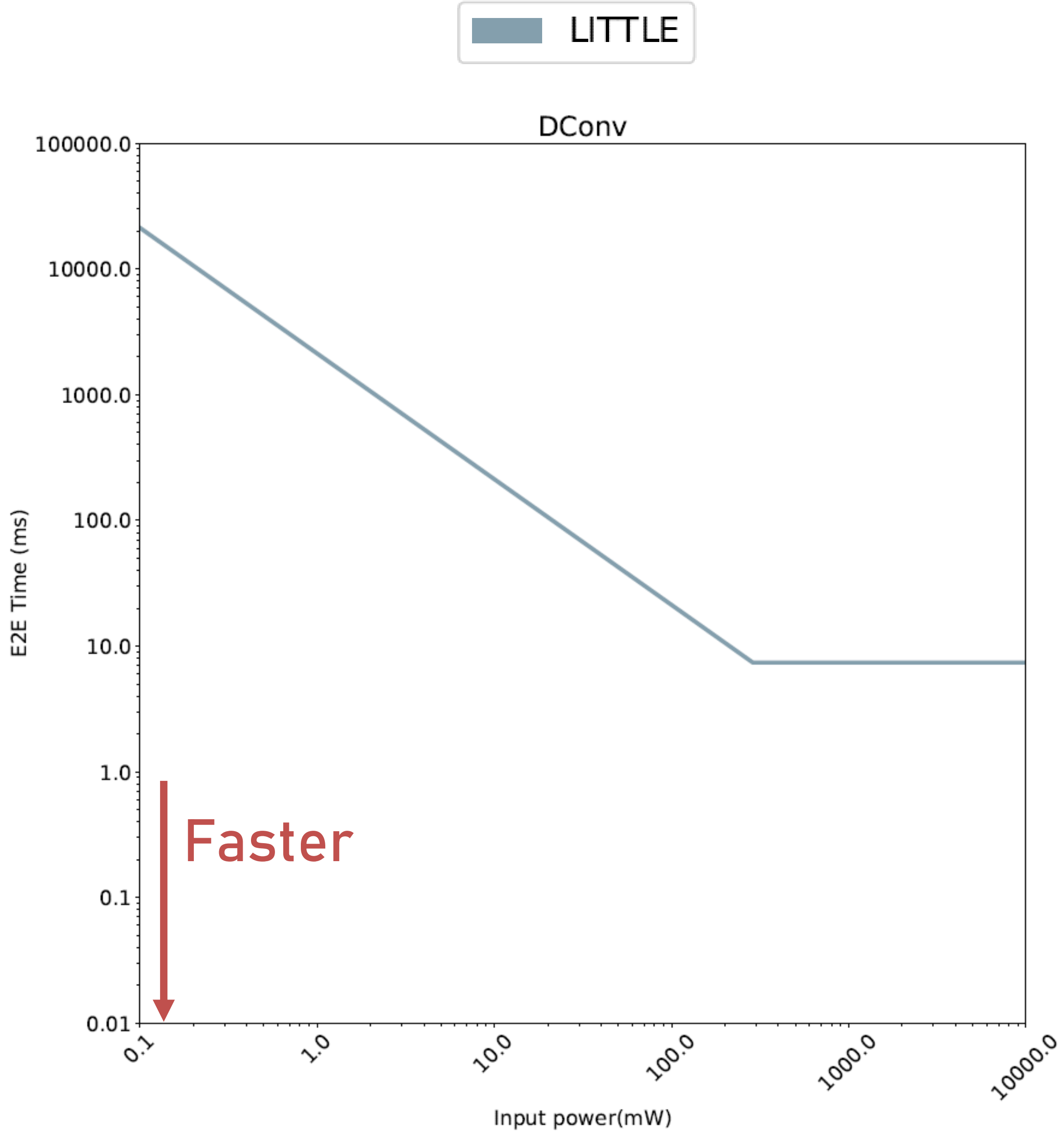
$$
\begin{aligned}
t_{e2e} &= \max(\, t_{execution}, t_{recharge}) \\
&= \max(\, t_{execution}, \frac{E_{execution}}{P_{input}})
\end{aligned}
$$



PHASE Implications

$$t_{e2e} = \max(t_{execution}, \frac{E_{exection}}{P_{input}})$$

1. End-to-end Performance varies with *input power*

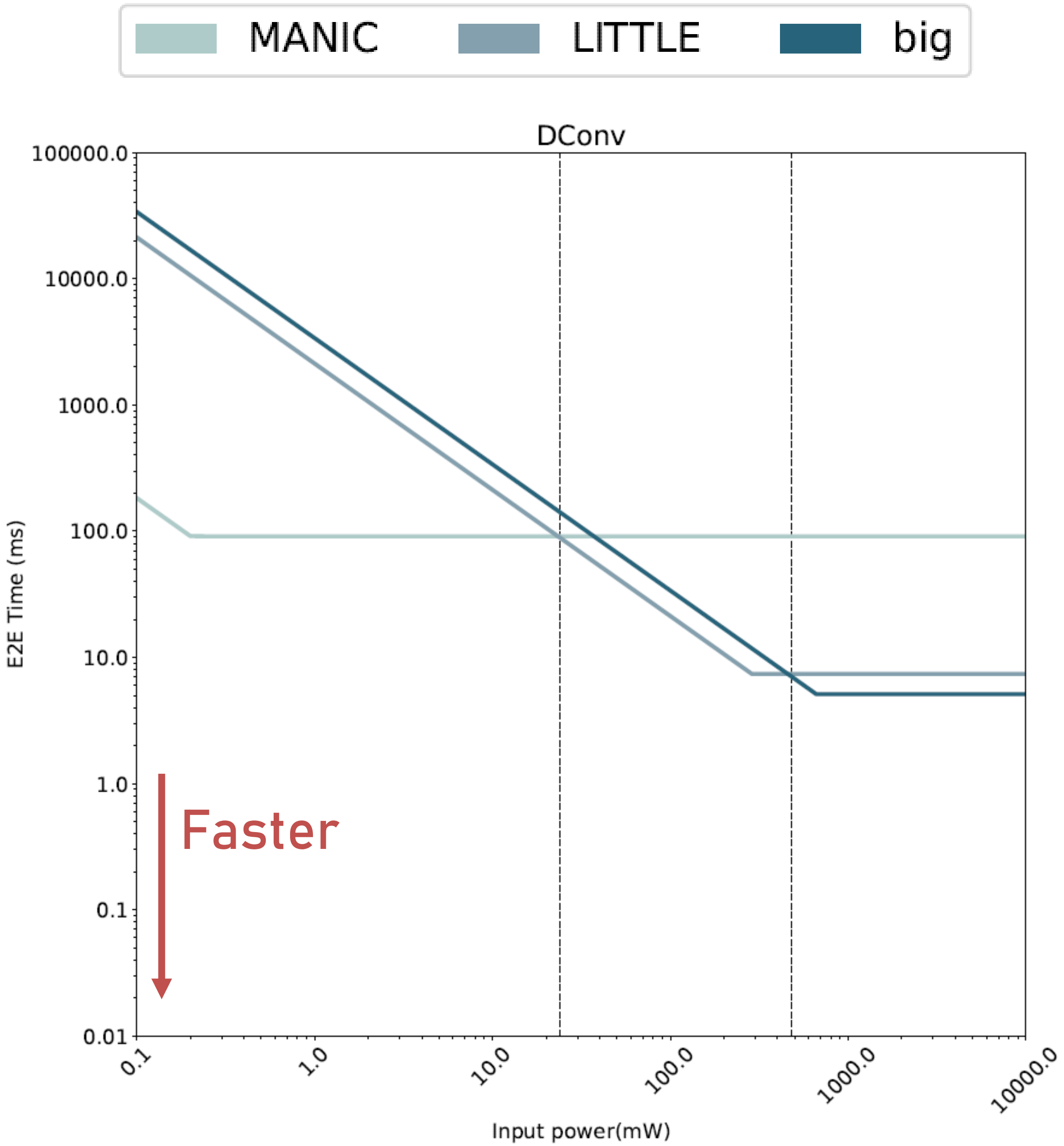


PHASE Implications

$$t_{e2e} = \max(\, t_{execution}, \frac{E_{exection}}{P_{input}})$$

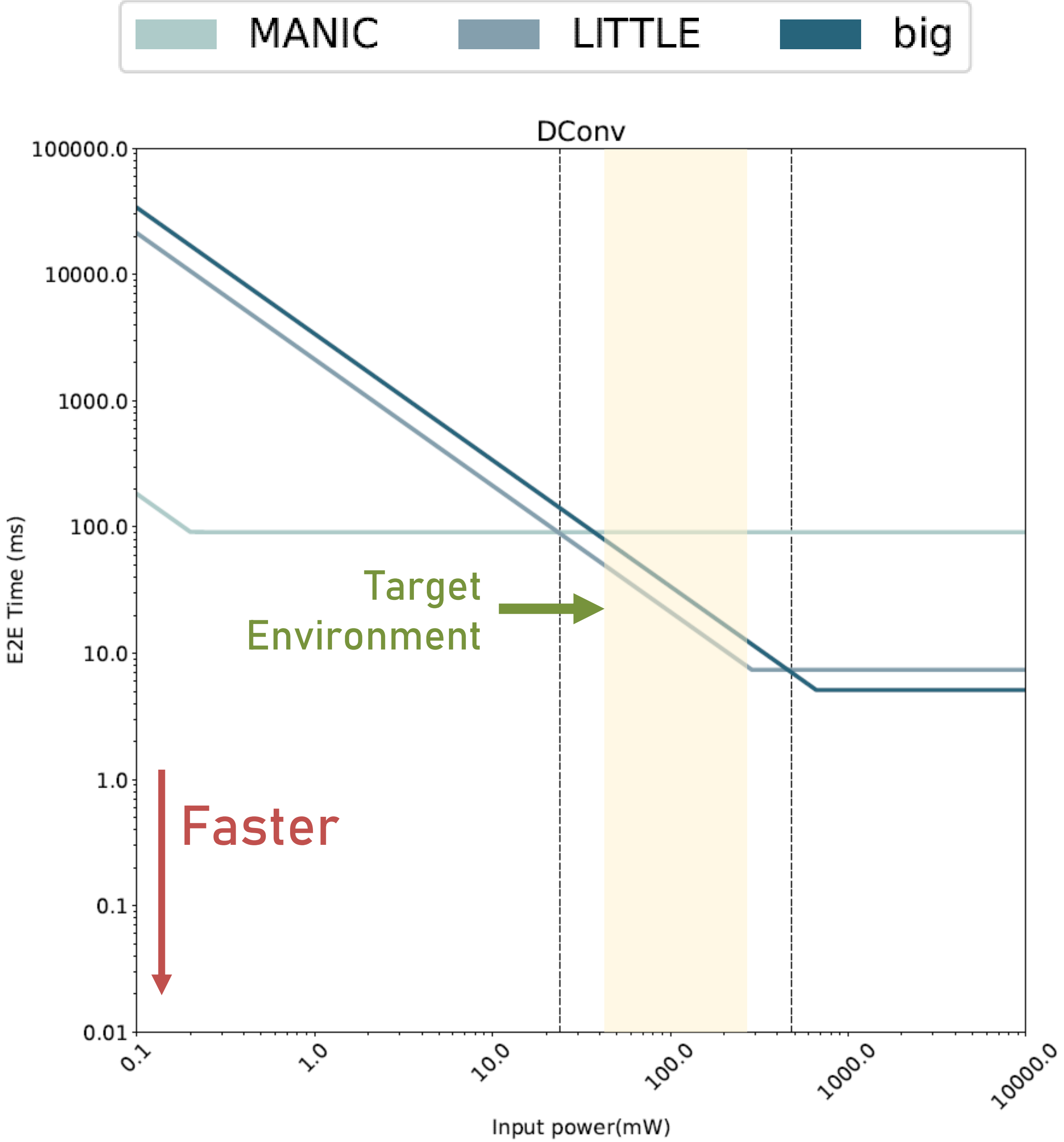
1. End-to-end Performance varies with input power

2. Best end-to-end performance can come from *different cores* as input power changes



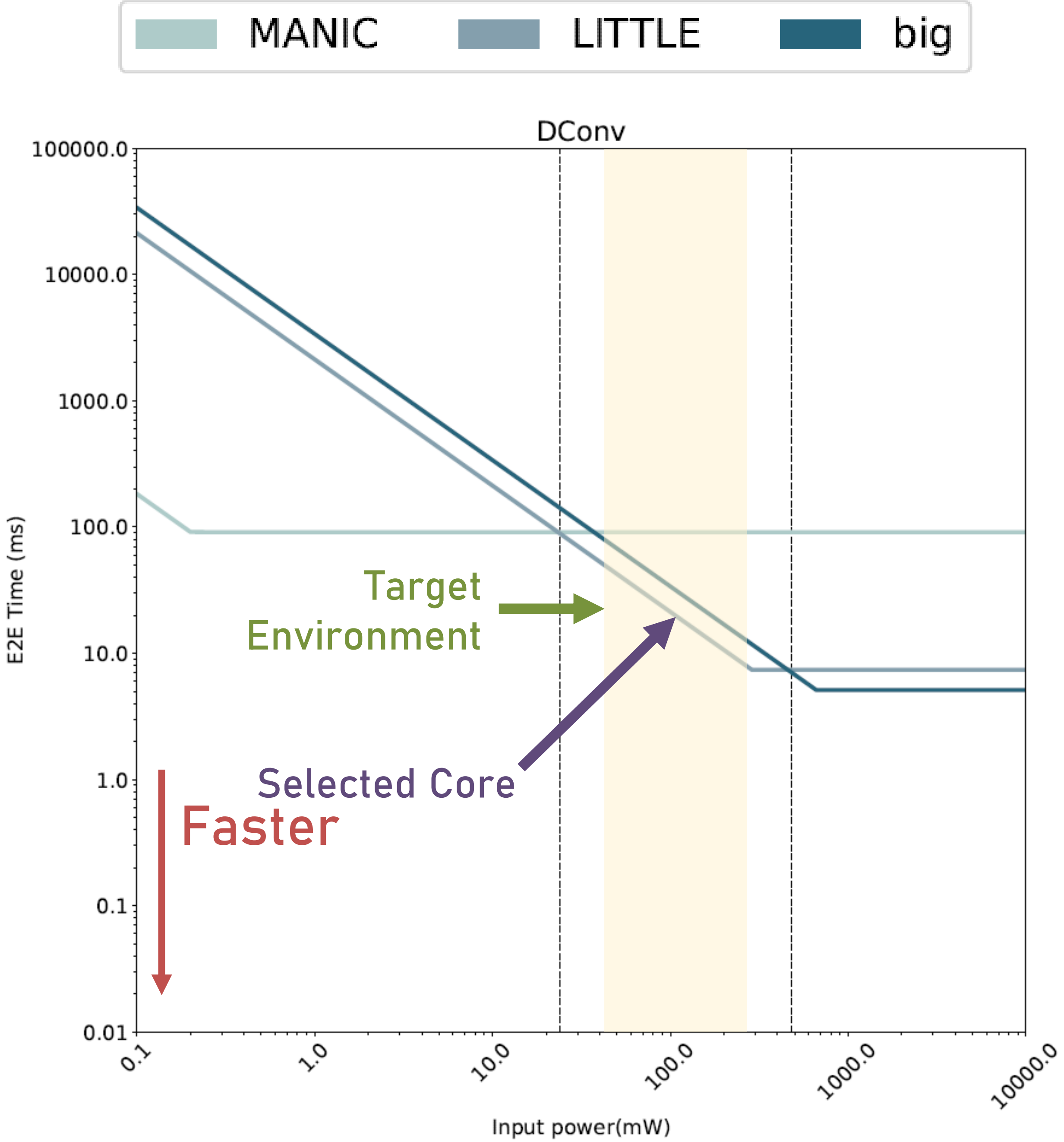
Using PHASE – Part 1

- If input power doesn't vary in target environment



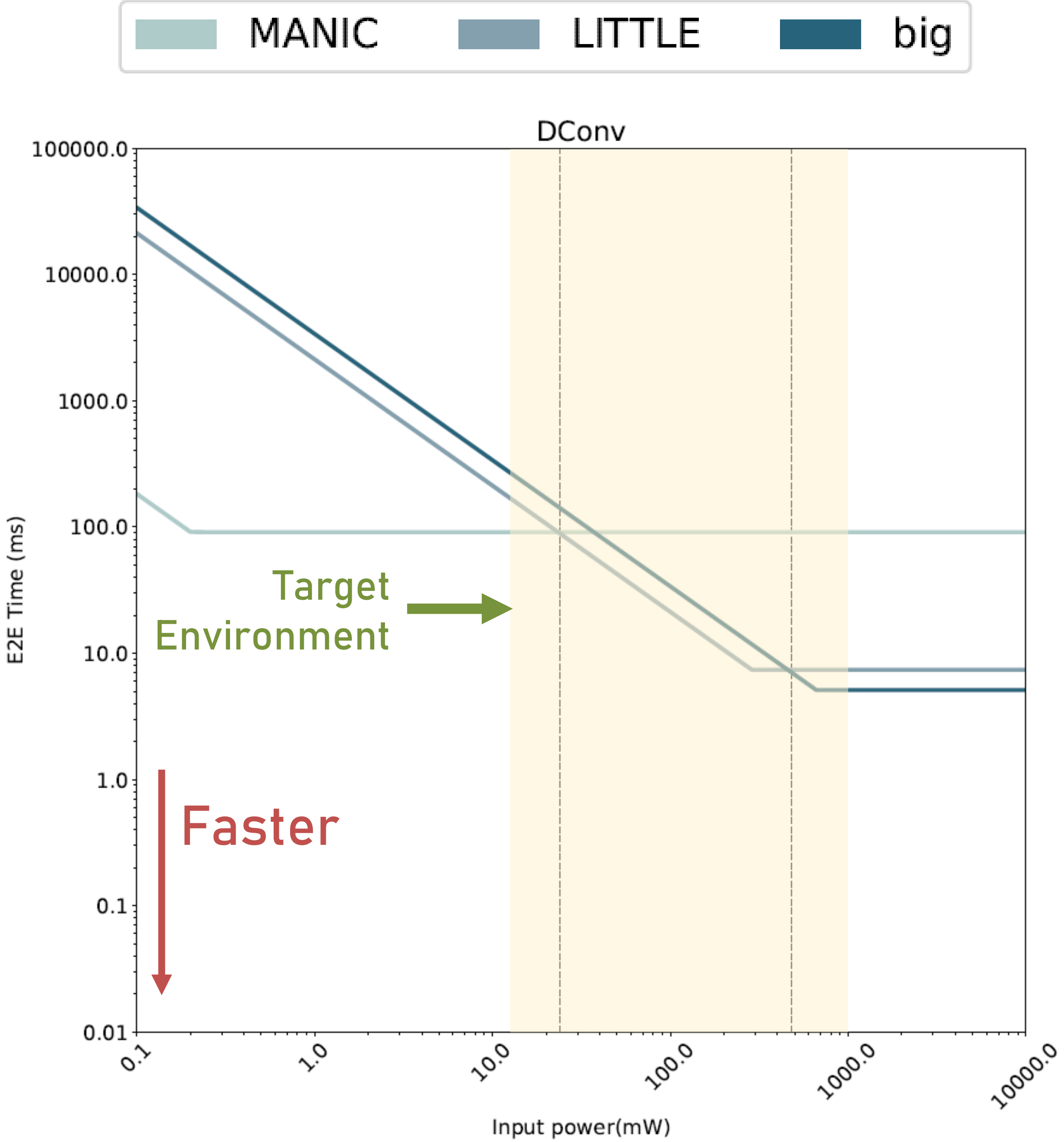
Using PHASE – Part 1

- If input power doesn't vary in target environment



Using PHASE – Part 2

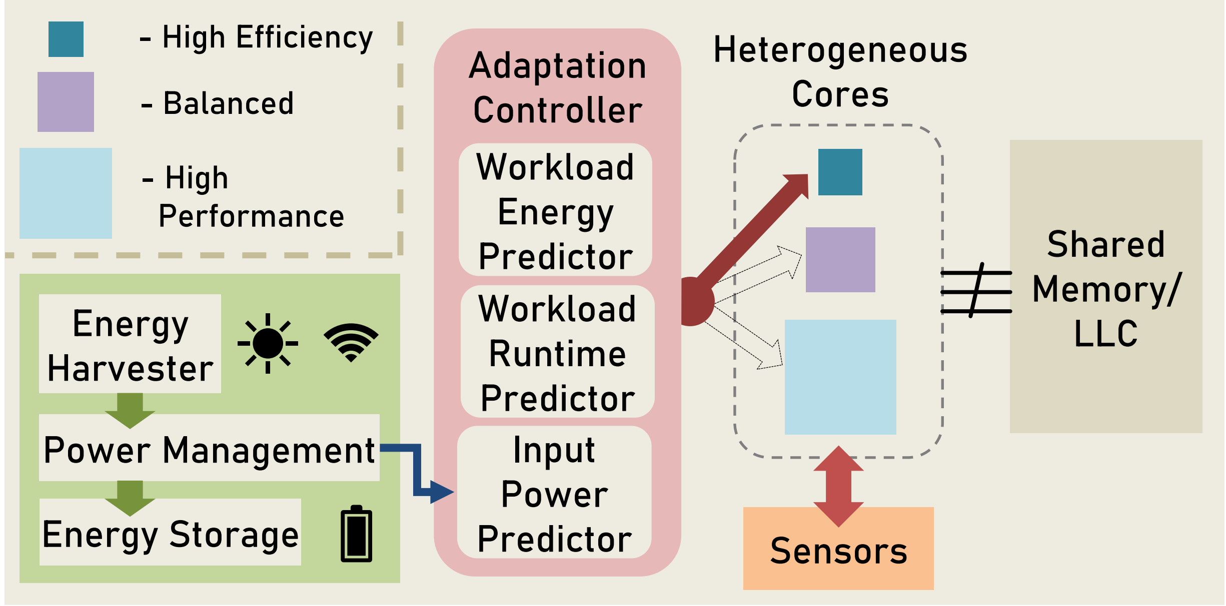
- If input power varies in target environment

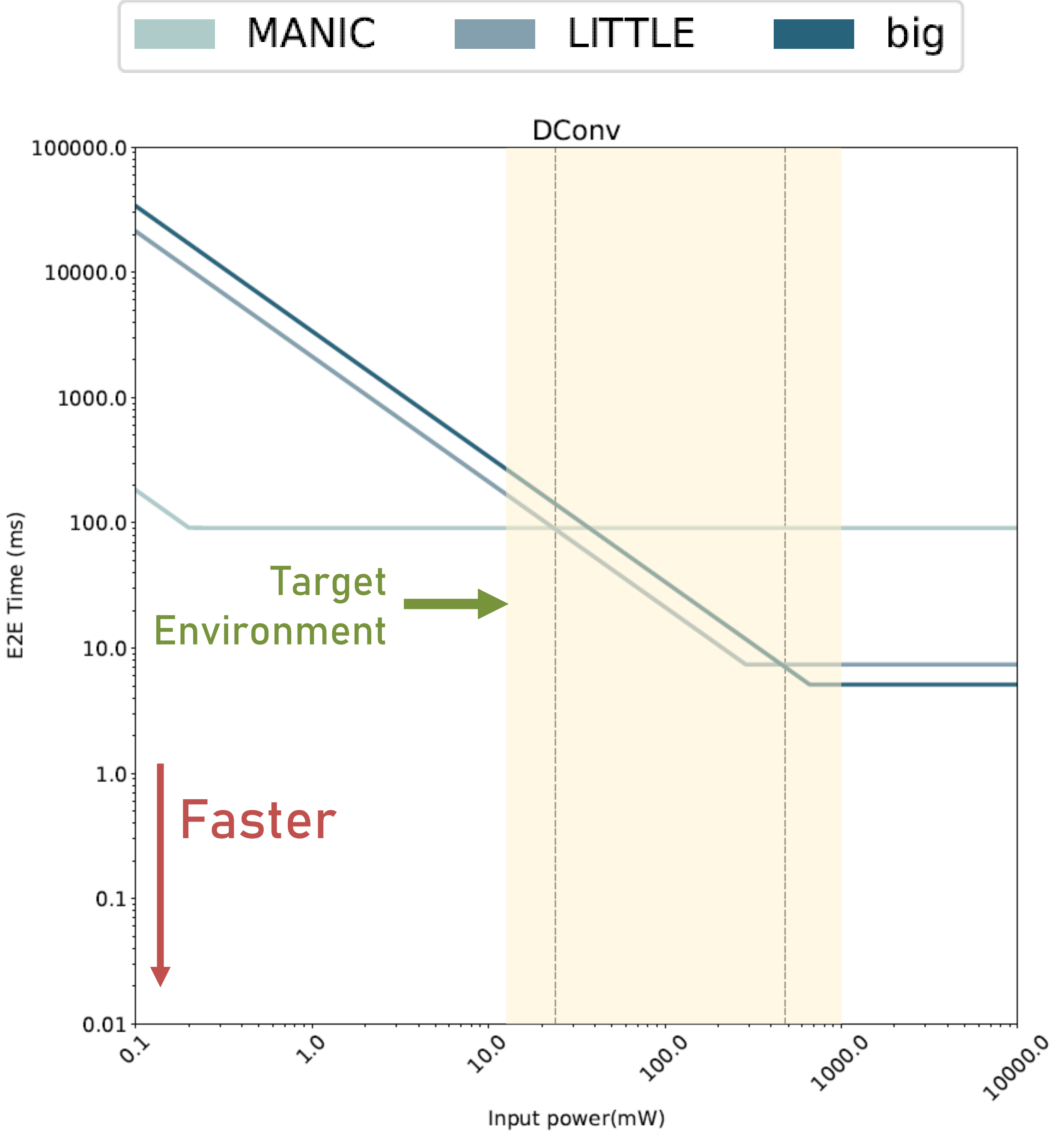


Using PHASE – Part 2

- If input power varies in target environment

PHASE-Online Architecture





Summary

- First performance model for EH devices
- Select fastest e2e core when input power doesn't vary much
- Dynamically switch to fastest e2e core when input power varies significantly

Thank You!

Experimental Results