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Leveraging Energy Cycle Regularity to Predict Adaptive Mode for Non-volatile Processors

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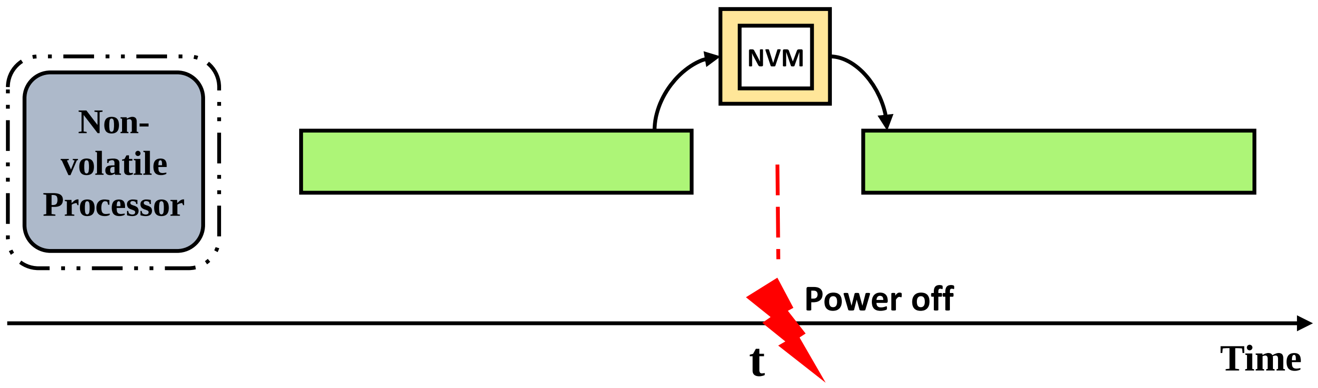
Outline

Introduction - NVPs without retention scheme

NVPs can accomplish data consistency during power failures

- System conducts backup when power is below preset threshold.
- After power resumes, the system recharges capacitor thoroughly first.
- NVPs then copy data from NVM back to volatile memory.



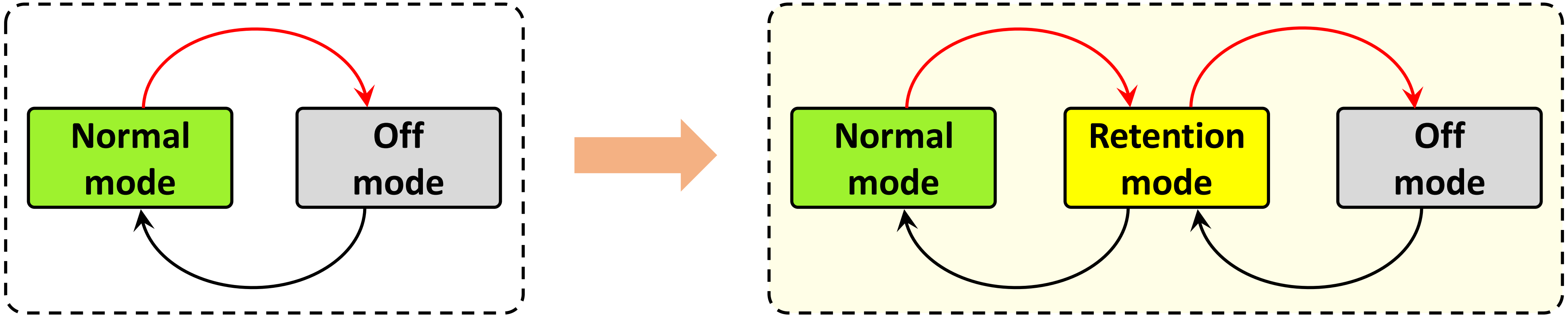
Introduction - NVPs with hardware support retention

During retention state, NVPs enter a sleep mode

- Data and registers are kept static and program execution stops.

A specific predictor determines whether perform retention or backup

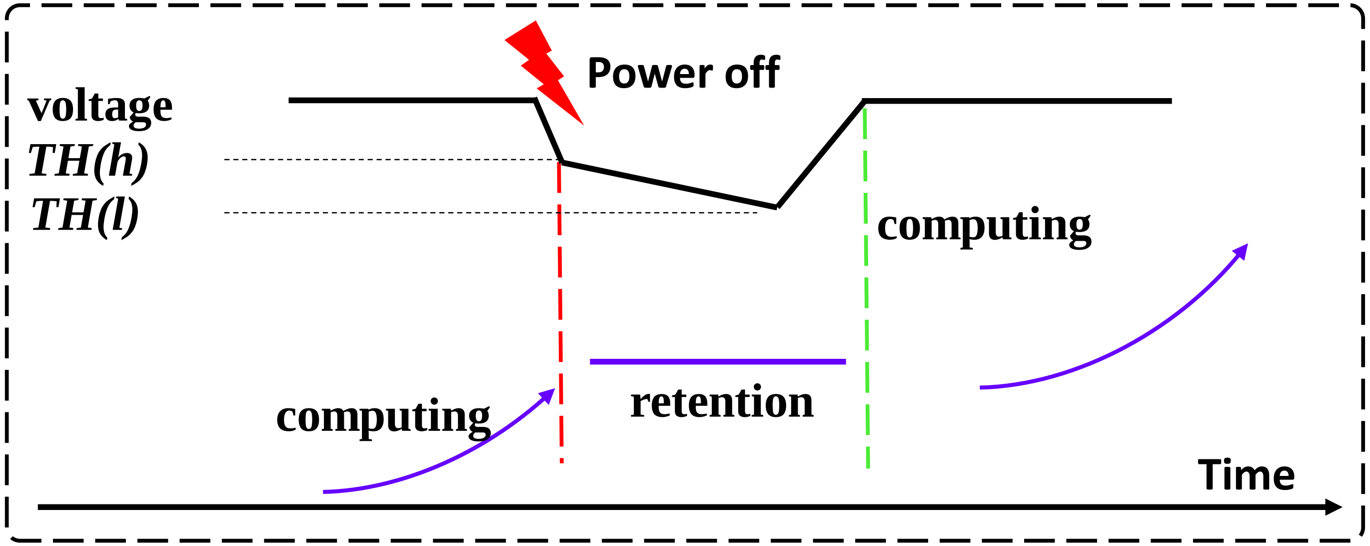
- If backup is adopted, system stores volatile data and enters OFF mode.
- Otherwise, it goes to RETENTION mode.



Introduction - NVPs with software support retention

“Dual-threshold” contains retention and backup threshold

- System enters retention and backup mode in order.
- If power resumes during retention, system restores directly.



Introduction – Related energy prediction algorithms

Previous energy predictions mostly focus on solar harvested-energy

- They implement prediction through the similarity among daily records.
- Improved mechanisms are proposed based on power measurements.

However

- The kinds of energy adaptive predictions are relatively onefold.

Introduction - Problem and idea

Problem:

- Hardware support retention leads to energy expenditure and slow process.
- Software support retention always enters retention mode on power failures.
- Related energy predictions focus on solar energy harvesting merely.

Idea:

- Leverage the regularity of energy waveforms to relieve energy waste.
- Determine an appropriate mode based on historical records.

Outline

1. Introduction

    1.1 NVPs without retention scheme

    1.2 NVPs with hardware support retention mode

    1.3 NVPs with software support retention mode

    1.4 Energy prediction algorithms

    1.5 Problem and idea

2. Methodology

    2.1 Phase 1: Select an adaptive mode

    2.2 Phase 2: Reexamine the decision of backup mode

    2.3 Correctness guarantee

3. Evaluation

    3.1 Experimental setup

    3.2 Experimental results

4. Conclusion

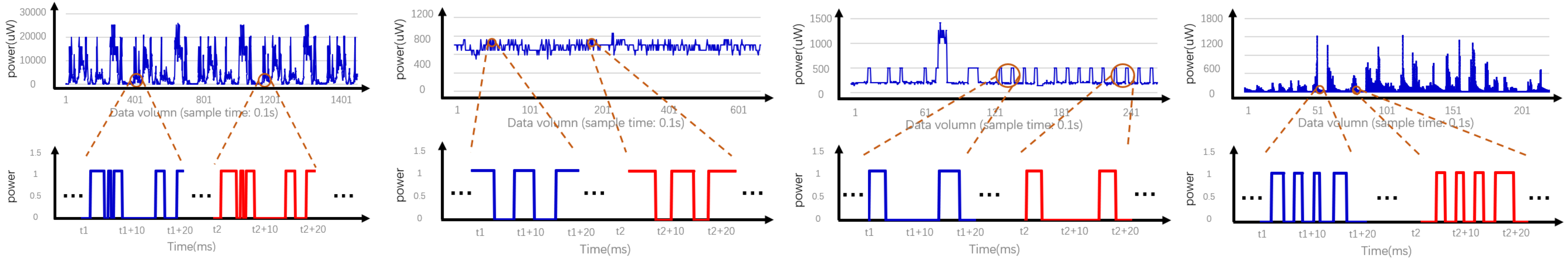
Methodology

- **Design overview**
- **Adaptive mode prediction**
  - Phase 1: Select an adaptive mode
  - Phase 2: Reexamine the decision of backup mode
- **Correctness guarantee**

Methodology

Changing ambient energy exhibits some kind of regularity

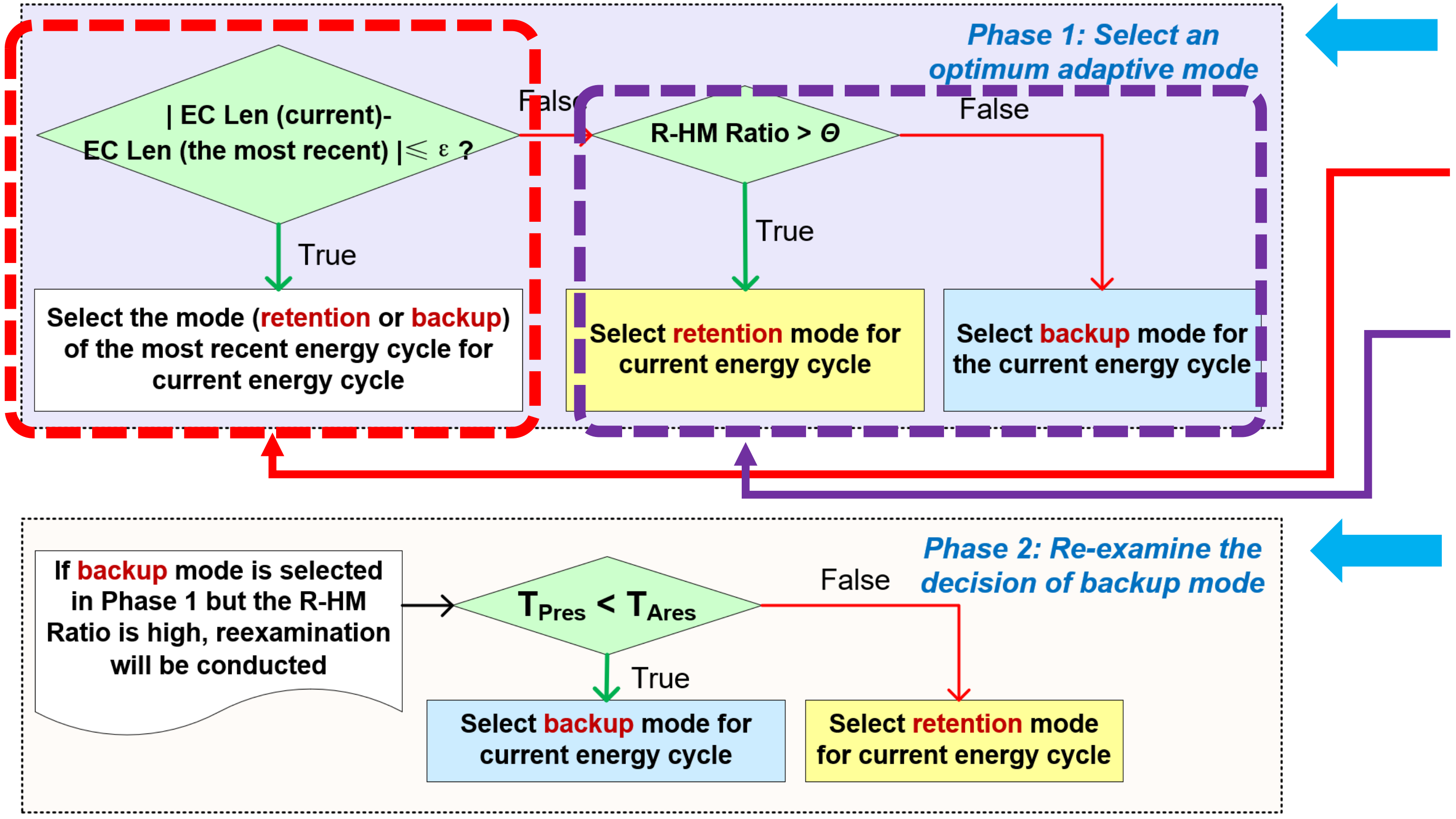
- Waveforms exhibit some kind of regularity.
- Regularity : the length of one energy cycle is very close to its near cycles.



TV-RF | WiFi (home) | WiFi (office) | Piezo

Methodology

Design overview



Phase 1 : Select an adaptive mode

Step 1 : check the feature similarity of current cycle with the most recent one.

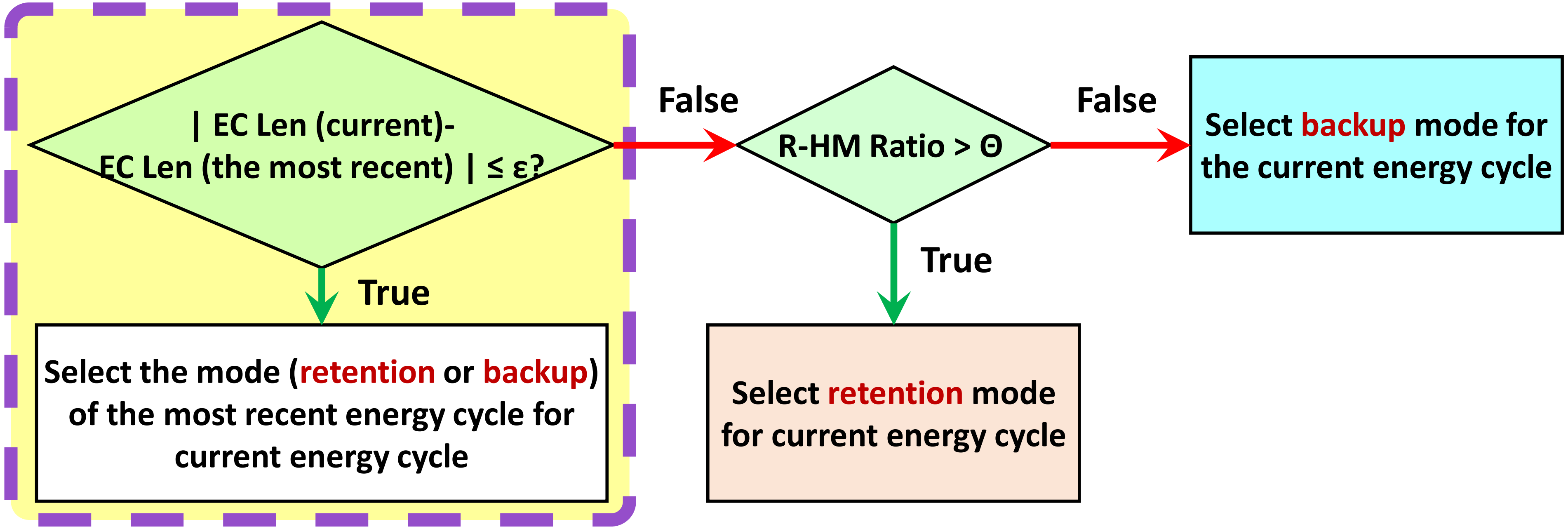
Step 2 : search further from a certain amount of historical records.

Phase 2 : Reexamine the decision of *backup* mode

Methodology

Phase 1: Select an adaptive mode

- **Step 1:** check the feature similarity of the current energy cycle with the most recent one.
  - |EC Len (current)-EC Len (the most recent)| **≤ ε**



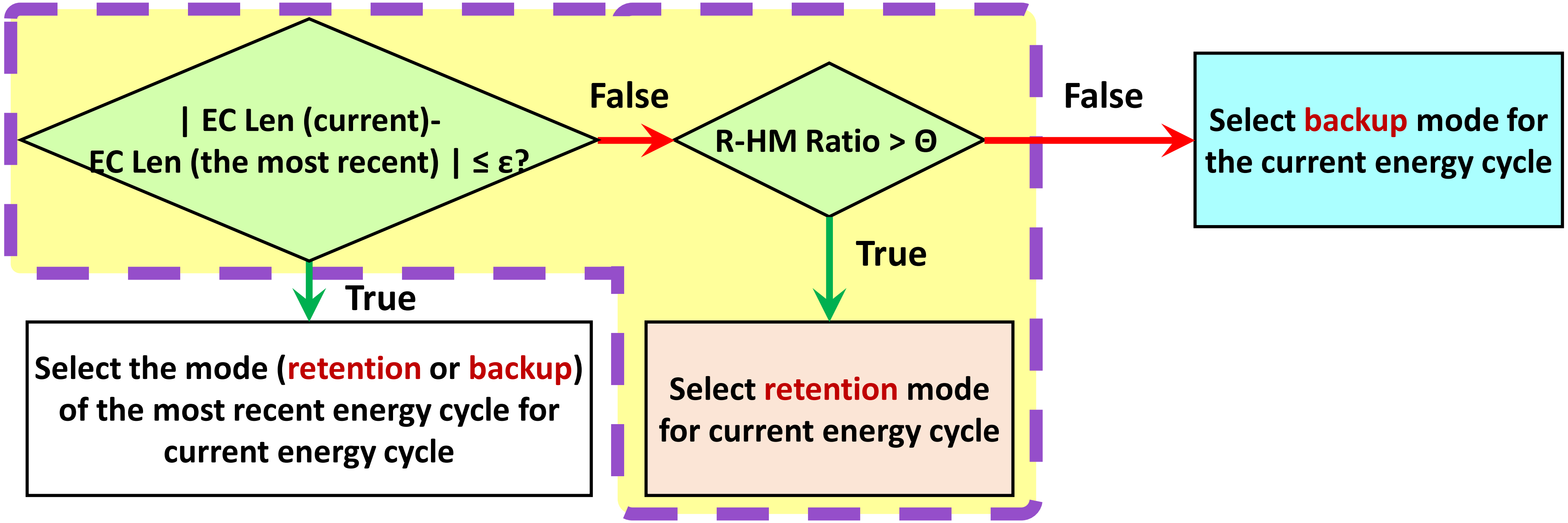
Methodology

outline	sampled energy	design overview	phase 1	phase 2	correctness guarantee	visual instance

Phase 1: Select an adaptive mode

- **Step 2**: search further from a certain amount of historical records.

  - |EC Len (current)-EC Len (the most recent)| > ε & R-HM Ratio > Θ



Methodology

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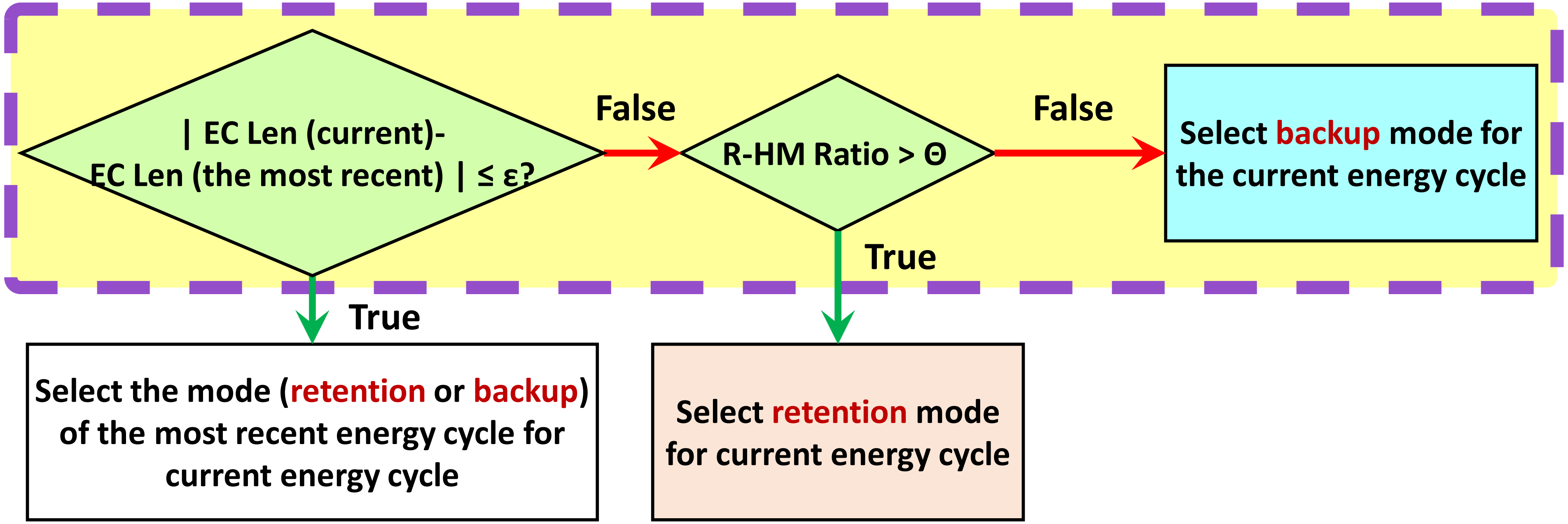
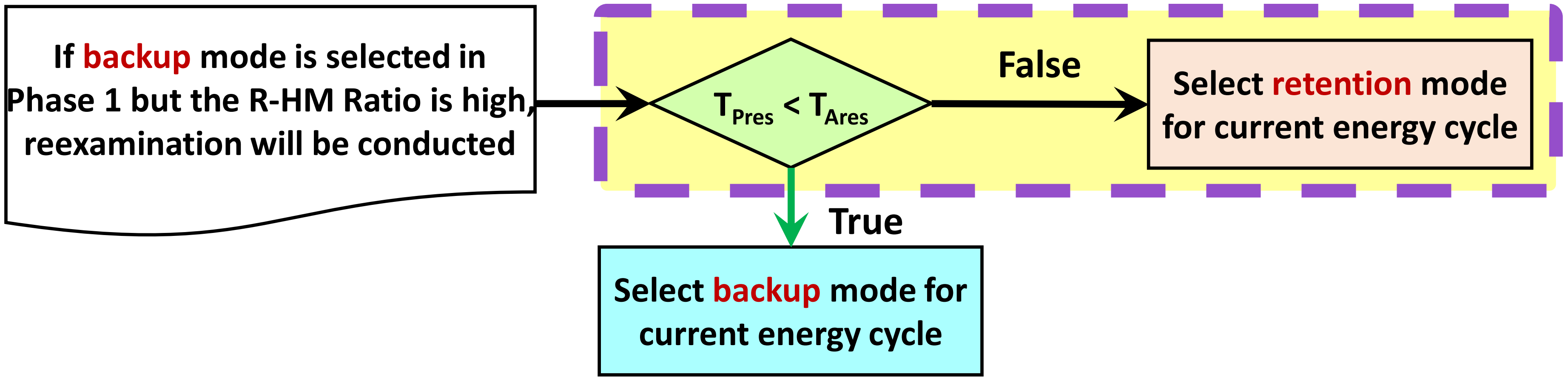


Methodology

■ Phase 2: Reexamine the decision of backup mode

(System could probably resume during retention if **backup** is selected in ***Phase 1*** with **high R-HM Ratio**.)

- $T_{Pres} \geq T_{Ares}$

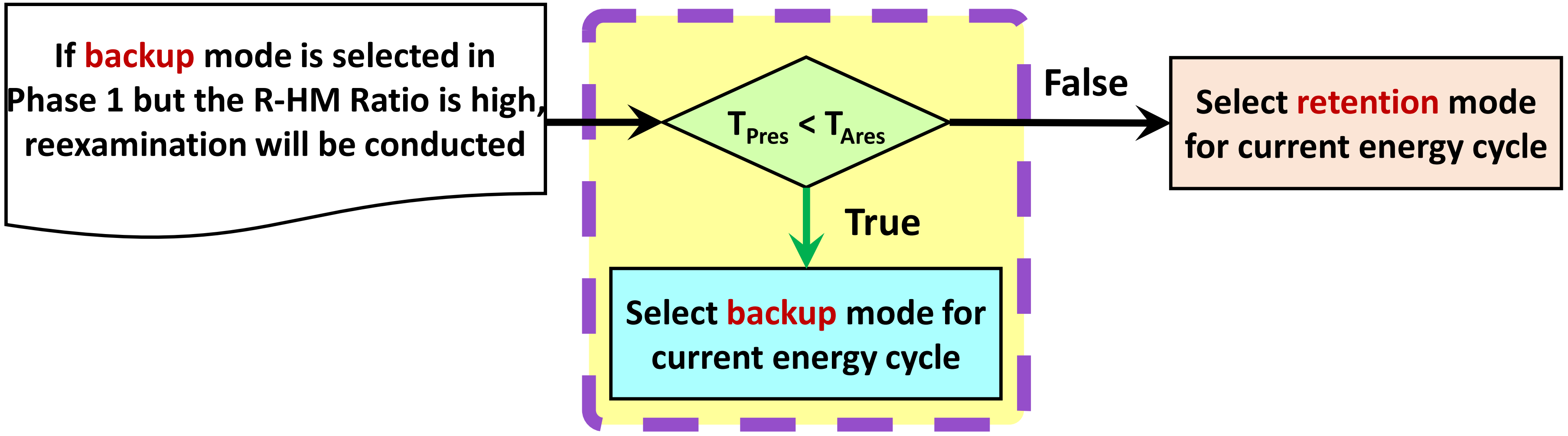


Methodology

Phase 2: Reexamine the decision of backup mode

(System could probably resume during retention if **backup** is selected in ***Phase 1*** with **high R-HM Ratio**.)

- T_{Pres} < T_{Ares}



Methodology

outline | sampled energy | design overview | phase 1 | phase 2 | **correctness guarantee** | visual instance

Correctness guarantee

Select backup mistakenly (retention should be the better choice**)**

- The system miss an opportunity to quickly recover.

Select retention mistakenly (power does not yet resume**)**

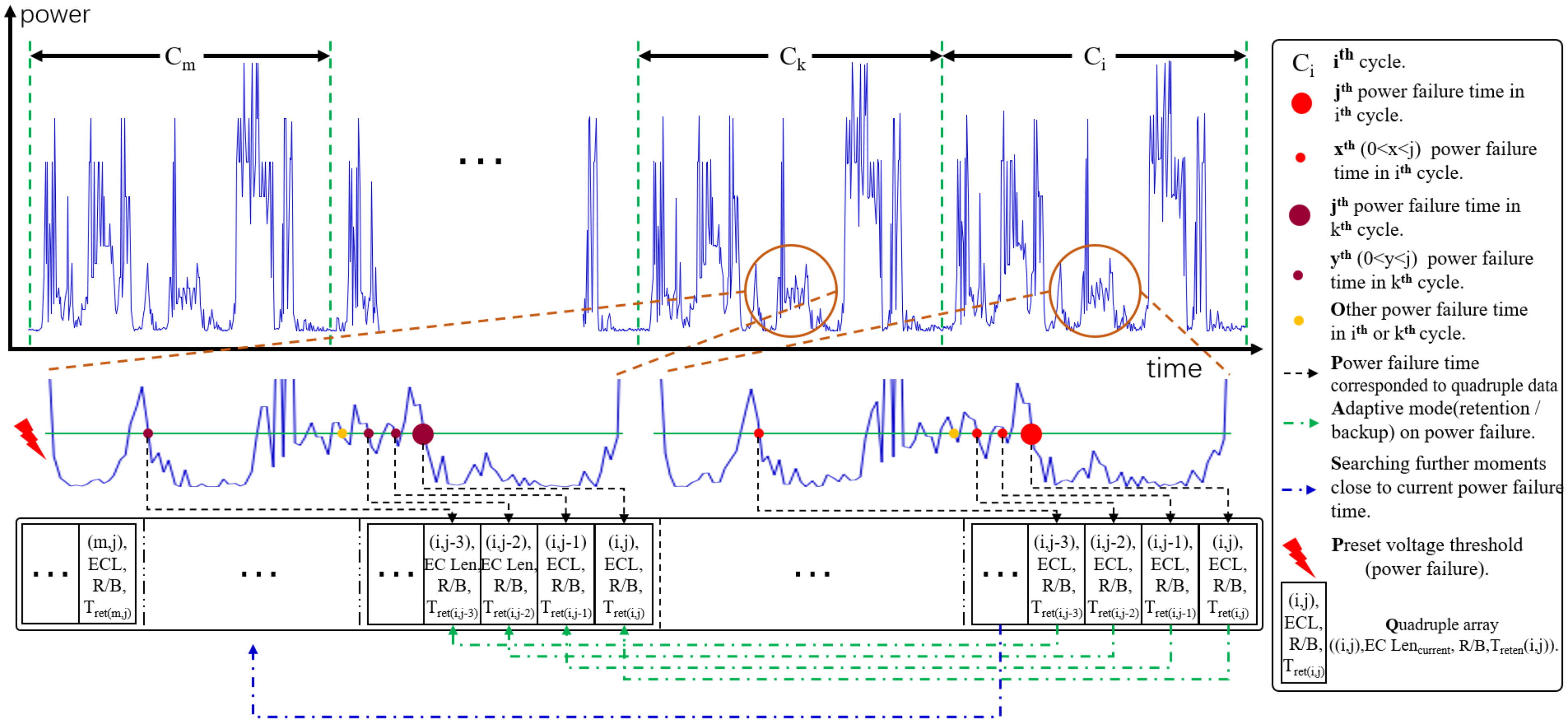
- The reserved energy is enough for storing the whole volatile data.

$$T_{retention} = \frac{E_{retention}}{P_{retention}} = \frac{E_{capacity} - E_{backup}}{P_{retention}}$$

Methodology

outline | sampled energy | design overview | phase 1 | phase 2 | correctness guarantee | **visual instance**

Prediction based on periodic mode logs based on *TV-RF*



Outline

Evaluation

Experimental setup

Parameter	Description
Processor	THU1010N
System frequency	217KHz
Memory	On-chip memory : SRAM
	On-chip NVM : FeRAM
	Register : Nonvolatile flip-flops

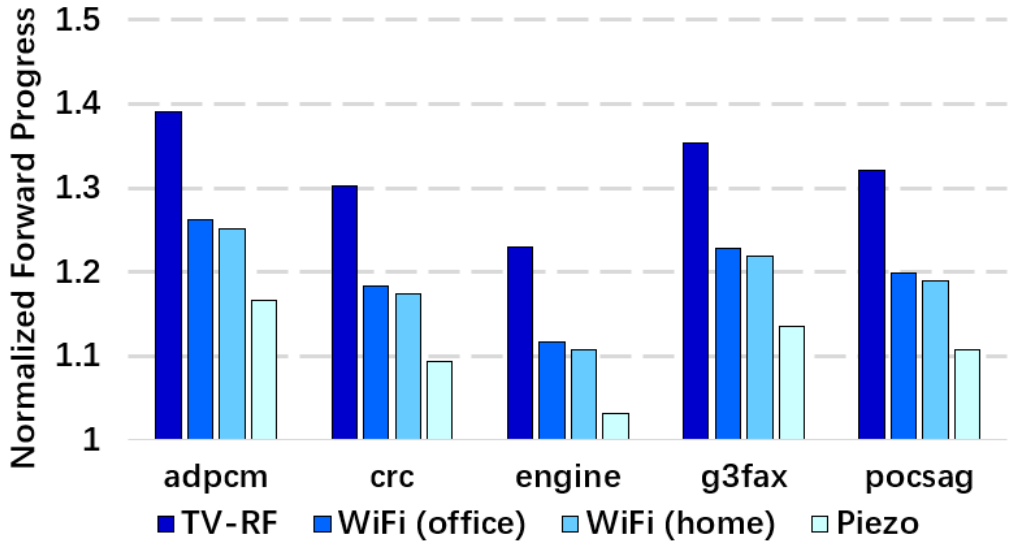
Energy	TV-RF	WiFi (home)	WiFi (office)	Piezo
Data Volume	1,800	421,820	65,000	500,000
ε (ms)	43.44	79.60	92.91	0.04
θ (%)	56.6	60.2	53.4	60.3

Measurements

- Execution forward progress
- Energy utilization efficacy

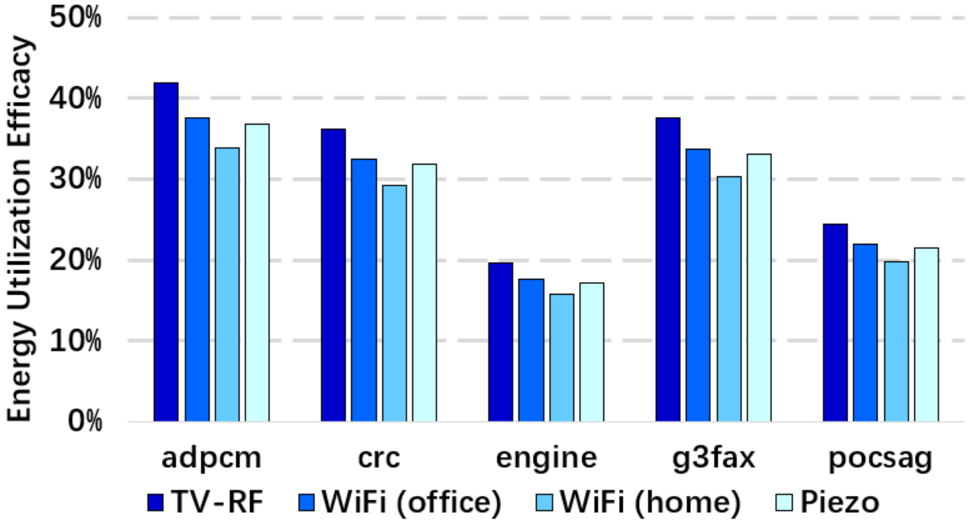
Evaluation

- **Execution forward progress**
  - Adaptive prediction scheme obtains more than 1.2X to 1.3X compared to the pure dual-threshold method.
  - When energy supplies are *WiFi (home)* and *WiFi (office)*, the forwardness of various benchmarks is very close.
  - Benchmark *adpcm* performs better than other benchmarks in different energy supply scenarios.



Evaluation

- **Energy utilization efficacy**
  - $$\eta_{eue} = \frac{E_{exe}}{E_{backup} + E_{exe} + E_{retention} + E_{resum}}$$
  - Based on *TV-RF*, the proposed implementation obtains improvement from 19.6% to 41.9%.
  - Energy utilization efficiency of various benchmarks performs better under *Piezo* than *WiFi (home)*, which is inconsistent with their improvement on forward progress respectively.



Outline

Conclusion

01 Background
- -- NVPs (without retention)
- -- NVPs (hardware&software retention)
- -- Energy prediction algorithms

02 Problem
- -- Energy expenditure
- -- Low decision process
- -- Complicated prediction

03 Idea
- ➢ Leverage the regularity of harvesting energy waveforms to relieve energy waste

04 Solution
- -- Phase 1: Select an adaptive mode
- -- Phase 2: Reexamine the decision

Results
- Execution forward progress: ↑1.38X
- Energy utilization efficiency: ↑41.9%

T H A N K S

Q & A